Demonstration Data Report

MTAD Demonstration Data Report
Former Camp San Luis Obispo
Magnetometer and EM61 MkII Surveys

MAY 2010

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Acronyms

Abbreviation	Definition
APG	Aberdeen Proving Ground
ASCII	American Standard Code for Information Interchange
AMTADS	Airborne Multi-sensor Towed Array Detection System
CD-R	Compact Disk - Recordable
CNG	California National Guard
COG	course-over-ground
DAQ	Data Acquisition (System)
DAS	Data Analysis System
DSB	Defense Science Board
DVD-R	Writable digital versatile disc
EMI	Electro-Magnetic Induction
ESTCP	Environmental Security Technology Certification Program
FQ	Fix Quality
FUDS	Formerly -Used Defense Site
GIS	Geographic Information System
GPO	Geophysical Prove-Out (area)
GPS	Global Positioning System
GSA	General Services Administration
HASP	Health and Safety Plan
HEAT	High Explosive Anti-Tank
HRR	Historical Records Review
Hz	Hertz
IMU	Inertial Measurement Unit
MM	Munitions Management
MR	Munitions Response
MRS	Munitions Response Site
MTADS	Multi-sensor Towed Array Detection System
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NMEA	National Marine Electronics Association
NRL	Naval Research Laboratory
nT	nanoTesla
Pd	Probability of Detection
POC	Point of Contact
PP	Peak-to-Peak
(PTNL,)AVR	Time, Yaw, Tilt, Range for Moving Baseline RTK NMEA-0183 message
(PTNL,)GGK	Time, Position, Position Type, DOP NMEA-0183 message
QA	Quality Assurance
QAO	Quality Assurance Officer

Acronyms (cont)

Abbreviation	Definition
QC	Quality Control
RMS	Root Mean Squared
RTK	Real Time Kinematic
SAIC	Science Applications International Corporation
SERDP	Strategic Environmental Research and Development Program
SI	International System of Units
SLO	San Luis Obispo
S/N	Signal / Noise
TBD	To Be Determined
USACE	United States Army Corps of Engineers
UTC	Universal Coordinated Time
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
YPG	Yuma Proving Ground

1.0 INTRODUCTION

1.1 BACKGROUND

In 2003, the Defense Science Board observed: “The … problem is that instruments that can detect the buried UXOs also detect numerous scrap metal objects and other artifacts, which leads to an enormous amount of expensive digging. Typically 100 holes may be dug before a real UXO is unearthed! The Task Force assessment is that much of this wasteful digging can be eliminated by the use of more advanced technology instruments that exploit modern digital processing and advanced multi-mode sensors to achieve an improved level of discrimination of scrap from UXOs [1].”

Significant progress has been made in classification technology over the past several years. To date however, testing of these approaches has been primarily limited to test sites with only limited application at live sites. Acceptance of these classification technologies requires demonstration of system capabilities at real UXO sites under real world conditions. Any attempt to declare detected anomalies to be harmless and requiring no further investigation will require demonstration to regulators of not only individual technologies, but an entire decision making process.

The FY06 Defense Appropriation contained funding for the “Development of Advanced, Sophisticated, Discrimination Technologies for UXO Cleanup” in the Environmental Security Technology Certification Program (ESTCP). ESTCP responded by conducting a UXO Discrimination Study at the former Camp Sibert, AL. The results of this first demonstration were very encouraging. Although conditions were favorable at this site, a single target-of interest (4.2-in mortar) and benign topography and geology, all of the classification approaches demonstrated were able to correctly identify a sizable fraction of the anomalies as arising from non-hazardous items that could be safely left in the ground. Of particular note, the contractor EM61-MK2 cart survey with analysis using commercially-available methods correctly identified more than half the targets as non-hazardous.

To build upon the success of the first phase of this study, ESTCP has sponsoring a second study in 2008 - 2009 at a site with more challenging topography and a wider mix of targets-of-interest. A range at the former Camp San Luis Obispo (SLO), CA has been identified for this demonstration.

1.2 OBJECTIVE OF THE OVERALL DEMONSTRATION

There are two primary objectives of this study:

1. Test and validate detection and discrimination capabilities of currently available and emerging technologies on real sites under operational conditions.

2. Investigate in cooperation with regulators and program managers how discrimination technologies can be implemented in cleanup operations.

Within each of these two overarching objectives, there are several sub-objectives.

Technical objectives of the Study

- Test and evaluate capabilities by demonstrating and evaluating individual sensor and discrimination technologies and processes that combine these technologies. Compare advanced methods to existing practices and validate the pilot technologies for the following:
    - Detection of UXOs
    - Identification of features that distinguish scrap and other clutter from UXO
    - Reduction of false alarms (items that could be safely left in the ground that are incorrectly classified as UXO) while maintaining P_d's acceptable to all
    - Ability to identify sources of uncertainty in the discrimination process and to quantify their impact to support decision making, including issues such as impact of data quality due to how data are collected
    - Quantify the overall impact on risk arising from the ability to clear more land more quickly for the same investment.
    - Include the issues of a dig-no dig decision process and related QA/QC issues
- Understand the applicability and limitations of the pilot technologies in the context of project objectives, site characteristics, suspected ordnance contamination
- Collect high-quality, well documented data to support the next generation of signal processing research

1.3 REGULATORY DRIVERS

ESTCP has assembled an Advisory Group to address the regulatory, programmatic and stakeholder acceptance issues associated with the implementation of discrimination in the MR process.

Objective of the Advisory Group

- Help the Program Office explore a UXO discrimination process that will be useful to regulators and managers in making decisions.
    - Under what conditions would you consider discrimination?

- What does a pilot project need to demonstrate for the community to consider not digging every anomaly as a viable alternative?
  - Methodology
  - Transparency
  - QA/QC requirements
  - Validation
- For implementation beyond the pilot project,
  - How should proposals to implement discrimination be evaluated?
    - Site suitability
      - Geology
      - Anomaly density
      - Site topography
      - Level of understanding of expected UXO types
    - Track record on like sites
    - Performance on test site or small subset of site
    - Understanding and management of uncertainties
  - Define data needs to support decisions, particularly with regard to decisions not to dig all detected anomalies
  - Define acceptable end-products to support discrimination decisions

- In support of the above, provide input and guidance to the Program Office
  - Pilot project objectives and flow-down to metrics
  - Flow down of program objectives to data quality objectives
  - Demonstration/Data collection plans
  - QA/QC requirements and documentation
  - Interpretation, Analysis, and Validation
  - Process flow for discrimination-based removal actions

1.4 SPECIFIC OBJECTIVES OF DEMONSTRATION

As part of the ESTCP UXO Classification Study, Nova Research, Inc. conducted two total coverage surveys of the 11.8 acre final demonstration site at the Former Camp SLO, CA Formerly-Used Defense Site (FUDS). These surveys were conducted using the Naval Research Laboratory (NRL) Multi-sensor Towed Array Detection System (MTADS) magnetometer and

EM61 MkII arrays. Characterization of the system responses to the items of interest was conducted using data collected both in a test pit and on an onsite calibration strip. These data were collected in accordance with the overall study objectives and demonstration plan. The minimum system response at the Study depth of interest was then used to extract threshold exceedances from the data sets. The data chips surrounding these threshold exceedances were analyzed using a physics-based dipole model. This document details the demonstration as executed at the former Camp SLO demonstration site, the data analyses conducted, and the generated data products.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

2.1.1 Magnetometer Array

The MTADS magnetometer array is a linear array of eight Cs-vapor magnetometer sensors (Geometrics, Inc., G-822ROV/A). The G-822A magnetometers employ an optically pumped Cesium-vapor atomic magnetic resonance system that functions as the frequency control element in an oscillator circuit [2]. The frequency of the magnetometer electrical oscillator, or Larmor frequency, varies directly with the ambient magnetic field at the sensor. The accurate measurement of the Larmor frequency therefore provides a precise measurement of the local magnetic field of the Earth. The Earth's magnetic field interacts with ferrous objects, inducing localized anomalies in the measured magnetic field.

The G-822A magnetometer produces a Larmor frequency output at 3.49872 Hz per nT. At the earth's surface, in a nominal 50,000 nT field, the Larmor frequency is about 175 kHz. The G-822A operates over the earth's magnetic field range of 20,000 to 100,000 nT. In the MTADS, a pair of Geometrics Supercounters provides 8 channels total of counting circuitry to collect the G-822A data from the array. The Larmor frequency output of each magnetometer is converted to local magnetic field (nT) and output via a serial data link to the data acquisition computer (DAQ), where the measurements are time-stamped and recorded.

2.1.2 EM61 MkII Array

The Geonics EM61 MkII sensor is a pulsed-induction sensor which transmits a short electromagnetic pulse (a unipolar rectangular current pulse with a 25% duty cycle) into the Earth. The instrument consists of two air-core coils housed in fiberglass, the transmitter and receiver electronics, an isolated power source, and an optional data logging device. The lower coil encapsulates both the transmitter coil and the main receiver coil. The upper (receiver only) coil is mounted 30-40 cm above the bottom coil. Metallic objects interact with the transmitted field which induces secondary fields in the objects. These secondary fields are then detected by the receiver coils. An EM61 MkII mounted on a test stand is shown in Figure 2-1.

Figure 2-1 – Geonics EM61 MkII coils on a test platform

The transmitter pulse repetition rate is 62.5 - 150 Hz [3,4]. The transmit pulse is approximately 3 milliseconds long with a linear ramp off on the order of 100 μs. The EM61 MkII electronics can be operated in one of two modes: 1) 4-channel ("4") mode with 4 time "gates" for the bottom receiver coil or 2) Differential ("D") mode, in which 3 time "gates" are measured from the bottom coil and one is measured from the top coil. The transient decay voltage profile is sampled in the four time windows (for one or two receiver coils, as is appropriate) and analog integrated. The analog-integrated voltages are then sampled by the instrument's analog-to-digital (A/D) converter. The analog integration step has a dynamic time response that both shifts and modifies the sensor's response.

The output of the pulsed-induction sensor can be sampled at rates up to 15 Hz, resulting in a data station spacing of approximately 15 cm at slow driving speeds. The analog integrated voltage is sampled each time the electronics receives a trigger event. The trigger can either be a hardware pulse or a trigger character sent via RS-232 from the data acquisition software. Each trigger event results in a binary data packet being sent via RS-232 to the data acquisition software. The details of the binary data packet format are given in the EM61 MkII documentation [3].

The transmit current changes in amplitude as the system battery discharges. The reported current is then used to normalize the voltage outputs to measurements made at the reference transmit current.

The NRL EM61 MkII Array is an overlapping array of three 1m x 1m EM61 coil sets with custom MkII electronics designed to increase the transmit power and to measure earlier portions of the decay. These modifications were made to improve the sensitivity of the system to smaller items and for improved compatibility with use as a towed array and are detailed in Section 5.3.3.

2.1.3 Development of the Technologies

The Chemistry Division of the Naval Research Laboratory has participated in several programs funded by SERDP and ESTCP whose goal has been to enhance the discrimination ability of

MTADS for both the magnetometer and EM-61 array configurations. The process was based on making use of both the location information inherent in an item's magnetometry response and the shape and size information inherent in the response to the time-domain electromagnetic induction (EMI) sensors that are part of the baseline MTADS in either a cooperative or joint inversion. As part of ESTCP Project 199812, a demonstration was conducted on a live-fire range, the 'L' Range at the Army Research Laboratory's Blossom Point Facility [5]. In 2001, a second demonstration was conducted at the Impact Area of the Badlands Bombing Range, SD [6] as part of ESTCP Project 4003. In all these efforts, our classification ability has been limited by the information available from the time-domain EMI sensor. The EM61 is a time-domain instrument with either a single gate to sample the amplitude of the decaying signal (MkI) or four gates relatively early in time (MkII). The first generation of the MTADS EM61 MkII array was demonstrated in 2001 [6] at the Badlands Bombing Range, SD with little demonstrable gain over the single decay of the MkI array. A second generation of the MkII array with updated electronics was constructed in 2003 as part of ESTCP Project 200413. The upgraded MTADS EM61 MkII array was demonstrated at both of the Standardized UXO Technology Demonstration Sites located at the Aberdeen and Yuma Test Centers in 2003 and 2004 [7]. Appendix D summarizes the Open Field scenario results of the APG and YPG demonstration. The Response stage results for the EM61 MkII Array from the APG Open Field Scenario are shown in Figure 2-2 broken out by munitions type. The depth of 100% detection is denoted by the blue bar and the depth of maximum detection is shown as the horizontal line. For some of the items, the 105-mm HEAT for example, these two depths are the same. For many of the items, the maximum depth of detection is below the depth of 100% detection.

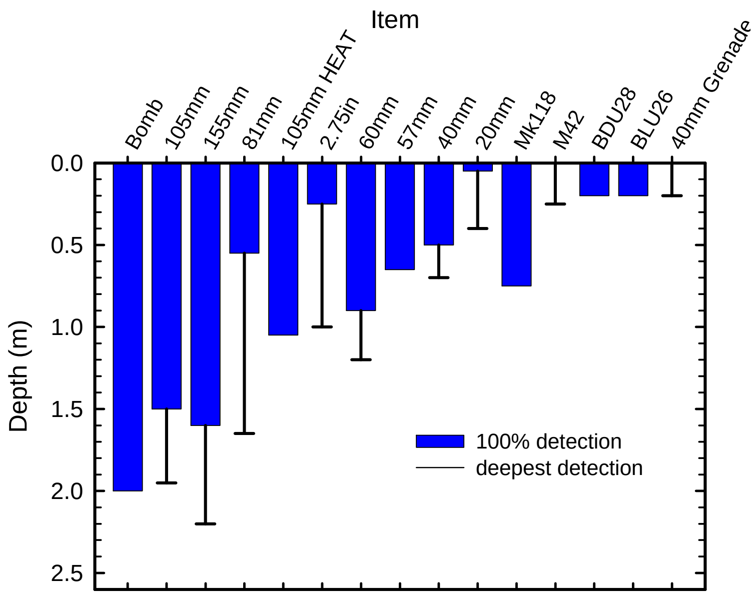


Figure 2-2 – MTADS EM61 MkII response stage results for the APG Open Field scenario broken out by munitions type

The MTADS EM61 MkII Discrimination Stage results from the APG Open Field are shown in Figure 2-3. The results are analyzed by excluding first items that were not covered by the survey or were within 2-m of another item and then further excluding items deeper than 11x their diameter. The exclusion of items at depths below 11x their diameter (presumably lower S/N anomalies) somewhat improves the discrimination performance. The 11x diameter rule is referenced in the figure as 'COE.'

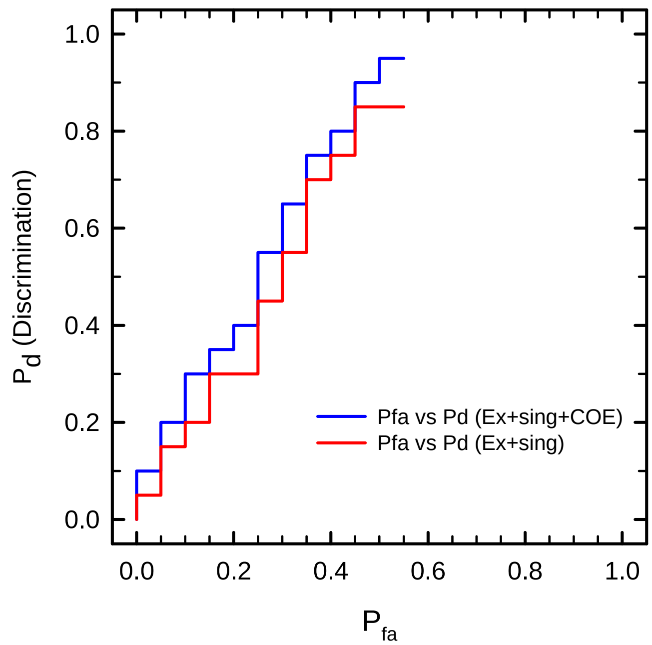


Figure 2-3 – MTADS EM61 MkII discrimination performance at the APG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

To make further progress on UXO discrimination, a sensor with more available information was required. The Geophex, Ltd. GEM-3 sensor is a frequency-domain EMI sensor with up to ten transmit frequencies available for simultaneous measurement of the in-phase and quadrature response of the target. In principle, there will be much more information available from a GEM-3 sensor for use in discrimination decisions. However, the commercial GEM-3 sensor is a hand-held instrument with relatively slow data rates and is thus not very amenable to rapid, wide area surveys. ESTCP Project MM-0033, Enhanced UXO Discrimination Using Frequency-Domain Electromagnetic Induction, was funded to overcome this limitation by integrating an array of GEM-3 sensors with the MTADS platform [8]. As this system is not part of the current demonstration, further details can be found in References 8 and 9.

Reference 7 compares the detection-only performance of the magnetometer, the second-generation MTADS EM61 MkII, and the GEMTADS arrays to other demonstrators at both of the Standardized UXO Technology Demonstration Sites. All three sensor arrays were also

demonstrated in the Spring of 2007 as part of the ESTCP UXO Discrimination Study at the Former Camp Sibert [9]. Data processing and the development of performance results for the various discrimination methodologies of the UXO Discrimination Study are currently ongoing.

The MTADS magnetometer array has been demonstrated at several seeded and live ranges sites over the last decade [10-15]. The MTADS magnetometer array has been selected previously to serve as the ground truth for several ESTCP-supported demonstrations [16,17,18]. Typical performance of the MTADS magnetometer array is documented in Reference 18.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

On large open ranges the vehicular MTADS provides an efficient survey technology. Surveys conducted with the magnetometer array often exceed production rates of 20 acres per day. Production rates for the EM systems are approximately one quarter that of the magnetometer system to maintain a sufficiently high data density. The survey speed is one half of that for the magnetometer system and to maintain data density, a second pass (orthogonal or interleaved) is required, halving the production again. UXO items with gauges larger than 20mm are typically detected to their likely burial depths. To reliably detect the smaller gauge munitions in this spectrum, the EM61 MkII array should be used rather than the magnetometer or GEM-3 arrays. Typically a human operator manually selects the data corresponding to individual anomalies. Each data segment is then processed by a physics-based algorithm incorporated into the MTADS Data Analysis System (DAS) software or an equivalent. For the ESTCP UXO Classification Study at the former Camp Sibert, anomalies that exceeded the sensor-specific detection threshold for each data set were identified and a subset of the anomalies from each sensor system selected for further analysis. The data surrounding each selected anomaly center were then extracted and submitted to the physics-based models resident in the MTADS DAS.

The presence of certain terrain features such as deep ravines without good crossing points, thick clusters of trees, and other non-navigable features such as large rocks and steep hill faces can limit the areas that can be surveyed. The presence of long barbed-wire fences without gates and deep ravines, steep hill and plateau faces without good access points can also slow survey operations by reducing survey line length and increasing travel time to traverse these obstacles. Site access and weather conditions can also have an impact on productivity.

3.0 PERFORMANCE OBJECTIVES

Performance objectives for the demonstration are given in Table 3-1 to provide a basis for evaluating the performance of the demonstrated technology. These objectives are for the technologies being demonstrated only. Overall project objectives are given in the overall demonstration plan generated by ESTCP.

Table 3-1 – Performance Objectives for This Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Quantitative Performance Objectives			
Site Coverage	Fraction of assigned coverage completed	Survey results	100% as allowed for by topography / vegetation
Data Density	Average number of data points per meter^2	Survey results	> 20 pts/m^2 for MkII > 60 pts/m^2 for Mag
Calibration Strip Results	System response consistently matches physics-based model	• System response curves • Daily calibration strip data	• ≤ 15% rms variation in amplitude • Down-track location ± 25cm • All response values fall within bounding curves
Detection of all Munitions of Interest	Percent detected of seeded items	• Location of seeded items • Anomaly list	At least 98% of seeded items detected
Location Accuracy	Average error and standard deviation in both axes for interrogated items	• Estimated location from analyses • Ground truth from validation effort	ΔN and ΔE < 10 cm σN and σE < 15 cm
Depth Accuracy	Standard deviation in depth for interrogated items	• Estimated location from analyses • Ground truth from validation effort	• ≥ 30cm: < 30% • < 30cm: ≤ 15 cm
Production Rate	Number of acres surveyed each day	• Survey results • Log of field work	5 acres/day for MkII 20 acres/day for Mag
Data Throughput	Throughput of data QC process	Log of analysis work	All data QC'ed on site and at pace with survey
Qualitative Performance Objective			
Reliability and Robustness	General Observations	Team feedback and system logs	Field team comes to work smiling

3.1 OBJECTIVE: SITE COVERAGE

The collection of a complete, high-quality data set with each sensor platform is critical to the downstream success of the UXO Classification Study. This objective considers one of the data quality issues, site coverage of the data collection.

3.1.1 Metric

Site coverage is defined as the fraction of the designated survey area surveyed by each sensor platform. Exceptions are to be made for topology / vegetation interferences.

3.1.2 Data Requirements

The spatial extend of the collected data will be compare to the original site boundaries as provided. Any interferences will be noted in the field log book.

3.1.3 Success Criteria

The objective will be considered met if 100% of the demonstration site is surveyed with the exception of areas that can not be surveyed due to topology / vegetation interferences.

3.2 OBJECTIVE: DATA DENSITY

The collection of a complete, high-quality data set with each sensor platform is critical to the downstream success of the UXO Classification Study. This objective considers one of the key data quality issues, the data density of the data collection.

3.2.1 Metric

Data density is defined as the number of data points collected during the data collection process per square meter. The performance is reported as the average value for the area surveyed.

3.2.2 Data Requirements

The collected data are used to determine the performance. The as-surveyed site boundaries, if different than the original ones provided, are also required.

3.2.3 Success Criteria

The objective will be considered met if the average data density for the final data set is > 20 points / square meter for the EM61 MkII array and > 60 points / square meter for the magnetometer array.

3.3 OBJECTIVE: CALIBRATION STRIP RESULTS

This objective supports the determination that each sensor system is in good working order and collecting physically valid data each day. The calibration strip is to be surveyed twice daily. The peak positive response of each emplaced item from each run is compared to both the aggregate average and to the physics-based response curves generated prior to data collection on site using each item of interest.

3.3.1 Metric

The reproducibility of the measured response of each sensor system to the items of interest and the comparison of the response to the response predicted by the physics-based model defines this metric.

3.3.2 Data Requirements

Response curves for each sensor / item of interest pair are used to document what the physics-based response of the system to the item should be. The tabulated peak response values from each survey of the Calibration Strip demonstrations the reproducibility and validity of the sensor readings.

3.3.3 Success Criteria

The objective will be considered met if all measured responses fall within the range of physically possible values based on the appropriate response curve. Additionally, the RMS variation in responses should be less than 15% of the measured response and the down-track location of the anomaly should be within 25 cm of the corresponding seeded item's true location.

3.4 OBJECTIVE: DETECTION OF ALL MUNITIONS OF INTEREST

Quality data should lead to a high probability of detecting the munitions of interest at the site.

3.4.1 Metric

The metric for this objective is the percentage of seed items that are detected using the specified anomaly selection threshold.

3.4.2 Data Requirements

An anomaly list is prepared for each sensor system. IDA personnel will score the detection probability of the seeded items for each list.

3.4.3 Success Criteria

This objective will be considered to be met if at least 98% of the seeded items are detected.

3.5 OBJECTIVE: LOCATION ACCURACY

An important measure of how efficiently any required remediation will proceed is the accuracy of predicted location of the targets marked to be dug. Large location errors lead to confusion among the UXO technicians assigned to the remediation costing time and often leading to removal of a small, shallow object when a larger, deeper object was the intended target.

3.5.1 Metric

The average error and standard deviation in both horizontal axes will be computed for the items which are selected for excavation during the validation phase of the study. This metric only applies to the fit result locations, not the threshold exceedance locations.

3.5.2 Data Requirements

The anomaly fit results and the ground truth for the excavated items will be required to determine the performance of the fitting routines in terms of the location accuracy.

3.5.3 Success Criteria

This objective will be considered as met if the average error in position for both Easting and Northing quantities is less than 10 cm and the standard deviation for both is less than 15 cm.

3.6 OBJECTIVE: DEPTH ACCURACY

An important measure of how efficiently any required remediation will proceed is the accuracy of predicted depth of the targets marked to be dug. Large depth errors lead to confusion among the UXO technicians assigned to the remediation costing time and often leading to removal of a small, shallow object when a larger, deeper object was the intended target.

3.6.1 Metric

The standard deviation of the predicted depths with respect to the ground truth will be computed for the items which are selected for excavation during the validation phase of the study. This metric only applies to the fit result locations, not the threshold exceedance locations.

3.6.2 Data Requirements

The anomaly fit results and the ground truth for the excavated items will be required to determine the performance of the fitting routines in terms of the predicted depth accuracy.

3.6.3 Success Criteria

Success for this objective will be considered in two categories. For predicted depths of greater than 30 cm, the success criteria will be an overall standard deviation of < 30%. For shallow

items with depth less than 30 cm, the success criteria will be an overall standard deviation of $\leq$ 15 cm.

3.7 OBJECTIVE: PRODUCTION RATE

This objective considers a major cost driver for the collection of high-density, high-quality geophysical data, the production rate. The faster quality data can be collected, the higher the financial return on the data collection effort.

3.7.1 Metric

The number of acres or hectares per day surveyed by each sensor system determines the production rate for a survey system.

3.7.2 Data Requirements

The metric can be determined from the combination of the field logs and the survey results. The field logs require the amount of time per day spent acquiring the data and the survey results determine the area surveyed in that time period.

3.7.3 Success Criteria

Typically, this objective will be considered met if average production rate is at least 5 acres / day for the EM61 MkII array and at least 20 acres / day for the magnetometer array. Given the small size of the demonstration site, 11.8 acres, if the demonstration is completed as per the schedule, this objective will be considered met.

3.8 OBJECTIVE: DATA THROUGHPUT

The collection of a complete, high-quality data set with each sensor platform is critical to the downstream success of the UXO Classification Study. This objective considers one of the key data quality issues, the ability of the data analysis workflow to support the data collection effort in a timely fashion. To maximize the efficient collection of high quality data, a series of MTADS standard data quality check are conducted during and immediately after data collection on site. Data which pass the QC screen are then processed into archival data stores. Anomaly selection and individual anomaly analyses are then conducted on those archival data stores. The data QC / preprocessing portion of the workflow needs to keep pace with the data collection effort for best performance.

3.8.1 Metric

The throughput of the data quality control workflow is at least as fast as the data collection process, providing real time feedback to the data collection team of any emergent issues.

3.8.2 Data Requirements

The data analysts log books will provide the necessary data for determining the success of this metric.

3.8.3 Success Criteria

This objective will be considered met if all collected data can be processed through the data quality control portion of the workflow in a timely fashion.

3.9 OBJECTIVE: RELIABILITY AND ROBUSTNESS

This objective represents an opportunity for all parties involved in the data collection process, especially the vehicle operator, to provide feedback on areas where the process could be improved.

3.9.1 Data Requirements

Discussions with the entire field team and other observations will be used.

4.0 SITE DESCRIPTION

The site description material reproduced here is taken from the recent SI report [19]. More details can be obtained in the report. The former Camp SLO is approximately 2,101 acres situated along Highway 1, approximately five miles northwest of San Luis Obispo, California. The majority of the area consists of mountains and canyons. The site for this demonstration is a mortar target on hilltop in MRS 05 (within former Rifle Range #12).

4.1 SITE SELECTION

This site was chosen as the next in a progression of increasingly more complex sites for demonstration of the classification process. The first site in the series, Camp Sibert, had only one target-of-interest and item “size” was an effective discriminant. At this site, there are at least four targets-of-interest: 60-mm, 81-mm, and 4.2-in mortars and 2.36-in rockets. This introduces another layer of complexity into the process.

4.2 SITE HISTORY

Camp SLO was established in 1928 by the State of California as a National Guard Camp. Identified at that time as Camp Merriam, it originally consisted of 5,800 acres. Additional lands were added in the early 1940s until the acreage totaled 14,959. From 1943 to 1946, Camp SLO was used by the U.S. Army for infantry division training including included artillery, small arms, mortar, rocket, and grenade ranges. According to the Preliminary Historical Records Review (HRR), there were a total of 27 ranges and thirteen training areas located on Camp SLO during World War II. Construction at the camp included typical dwellings, garages, latrines, target houses, repair shops, and miscellaneous range structures. Following the end of World War II, a small portion of the former camp land was returned to its former private owners. The U.S. Army was making arrangements to relinquish the rest of Camp SLO to the State of California and other government agencies when the conflict in Korea started in 1950. The camp was reactivated at that time.

The U.S. Army used the former camp during the Korean War from 1951 through 1953 where the Southwest Signal Center was established for the purpose of signal corps training. The HRR identified eighteen ranges and sixteen training areas present at Camp SLO during the Korean War. A limited number of these ranges and training areas were used previously during World War II. Following the Korean War, the camp was maintained in inactive status until it was relinquished by the Army in the 1960s and 1970s. Approximately 4,685 acres was relinquished to the General Services Administration (GSA) in 1965. GSA then transferred the property to other agencies and individuals beginning in the late-1960s through the 1980s; most of which was transferred for educational purposes (California Polytechnic State University and Cuesta College). A large portion of Camp SLO (the original 5,880 acres) has been retained by the California National Guard (CNG) and is not part of the FUDS program.

4.3 SITE TOPOGRAPHY AND GEOLOGY

The Camp SLO site consists mainly of mountains and canyons classified as grassland, wooded grassland, woodland, or brush. A major portion of the site is identified as grassland and is used primarily for grazing. Los Padres National Forest (woodland) is located to the north-northeastern portion of the site. During the hot and dry summer and fall months, the intermittent areas of brush occurring throughout the site become a critical fire hazard.

The underlying bedrock within the Camp SLO site area is intensely folded, fractured, and faulted. The site is underlain by a mixture of metamorphic, igneous, and sedimentary rocks less than 200 million years old. Scattered throughout the site are areas of fluvial sediments overlaying metamorphosed material known as Franciscan mélange. These areas are intruded by plugs of volcanic material that comprise a chain of former volcanoes extending from the southwest portion of the site to the coast. Due to its proximity to the tectonic interaction of the North American and Pacific crustal plates, the area is seismically active.

A large portion of the site consists of hills and mountains with three categories of soils occurring within: alluvial plains and fans; terrace soils; and hill/mountain soils. Occurring mainly adjacent to stream channels are the soils associated with the alluvial plains and fans. The slope is nearly level to moderately sloping and the elevation ranges from 600 to 1,500 feet. The soils are very deep and poorly drained to somewhat excessively drained. Surface layers range from silty clay to loamy sand. The terrace soils are nearly level to very steep and the elevations ranges from 600 to 1,600 feet. Soils in this unit are considered shallow to very deep, well drained, and moderately well drained. The surface layer is coarse sandy loam to shaley loam. The hill/mountain soils are strongly sloping to very steep. The elevation ranges from 600 to 3,400 feet. The soils are shallow to deep and excessively drained to well drained with a surface layer of loamy sand to silty clay.

4.4 MUNITIONS CONTAMINATION

A large variety of munitions have been reported as used at the former Camp SLO. Munitions debris from the following sources was observed throughout MRS 05 during the 2007 SI:

- 4.2-inch white phosphorus mortar
- 4.2-inch mortar base plate
- 3.5-inch rocket
- 37mm projectile
- 75mm projectile
- flares found of newer metal; suspected from CNG activities
- 105mm projectile
- 60mm mortar
- 81mm mortar
- Practice bomb
- 30 cal. casings and fuzes

At the particular site of this demonstration, 60-mm, 81-mm, and 4.2-in mortars and mortar fragments have been observed. During the initial EM61 MkII cart survey, two 2.36-in rockets were found on the surface. The excavation of two 50’ x 50’ grids in October 2008, as part of the

preparatory activities, has confirmed these observations and provided information on the depths of munitions at this target site.

4.5 SITE GEODETIC CONTROL INFORMATION

The 11.8-acre demonstration site is shown in Figure 4-1 as a series of included 30m x 30m cells with a topographical map as the background. The cells are color-coded based on the data collection systems that collected data on them, tan color for all systems and blue for vehicular systems only. An interior area is excluded due to rock outcroppings and the local slope. There are three control point monuments available near the site for use as GPS base station points established by Cannon Associates, of San Luis Obispo, CA referenced against nearby CALTRANS monument “A1315” [20]. The positions are listed in Table 4-1. Figure 4-2 shows the locations of monuments “A1315” and “ESTCP” with respect to the demonstration site. Monuments “MM” and “BUD” are located within 10m of “ESTCP” and are not shown for clarity. The horizontal datum for all values is NAD83. The vertical control is referenced to the NAVD88 datum and the Geoid03 geoid. Latitude and Longitude are given in degrees / minutes / seconds. Northing and Easting values are given in UTM Zone 10 (meters).

Table 4-1 – Geodetic Control at the Former Camp San Luis Obispo Demonstration Site

ID	Latitude (NAD83, deg)	Longitude (deg) (NAD83, deg)	Elevation (m)	Northing (UTM Zone 10, m)	Easting (UTM Zone 10, m)	HAE (m)
ESTCP	35º 20' 37.77465" N	120º 44' 25.95073" W	113.69	3,913,515.94	705,330.89	76.01
MM	35º 20' 37.53766" N	120º 44' 25.89483" W	113.54	3,913,508.67	705,332.47	75.81
BUD	35º 20' 37.61603" N	120º 44' 26.18134" W	113.66	3,913,510.92	705,325.18	75.93

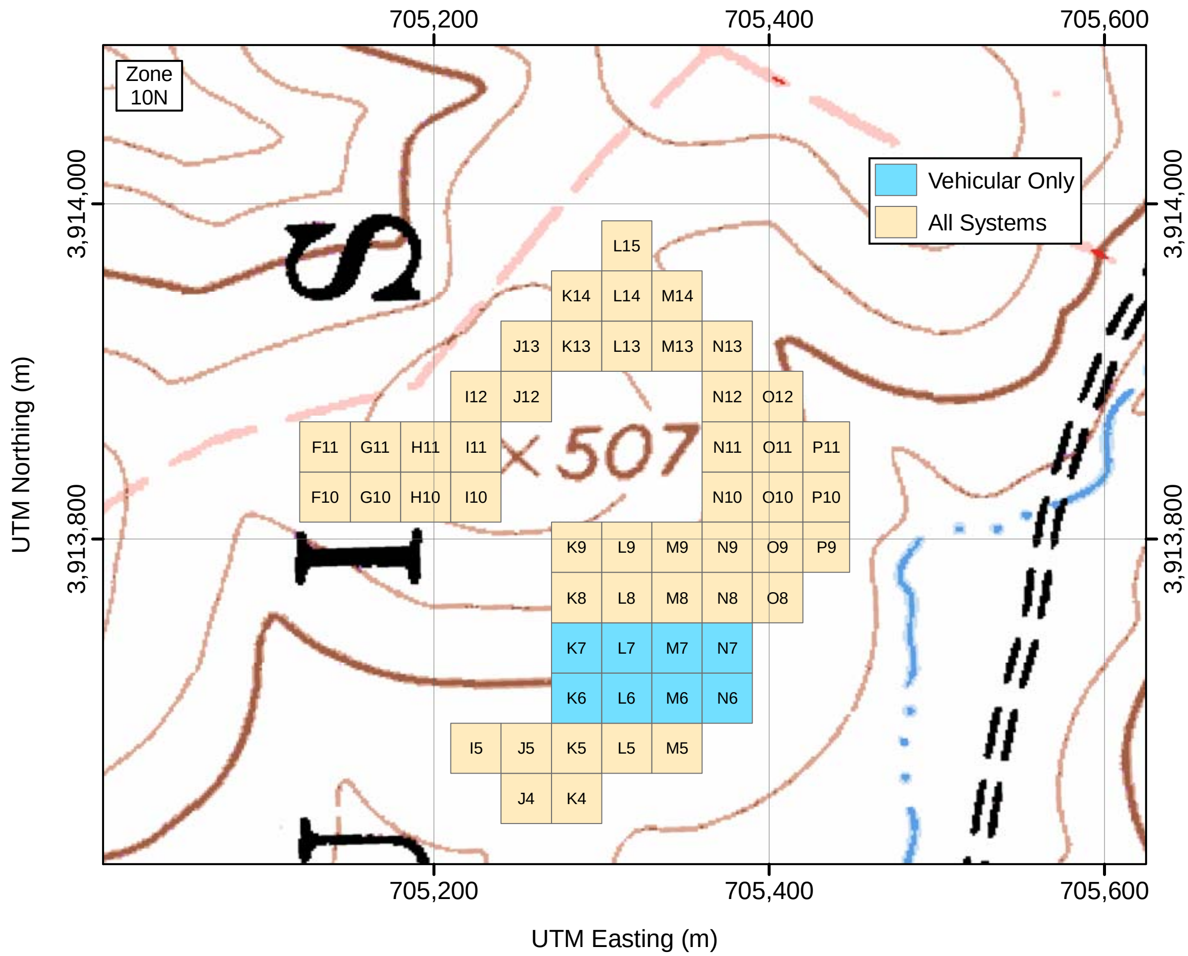


Figure 4-1 – ESTCP UXO Classification Study demonstration site at the former Camp San Luis Obispo. The site is shown as a series of included 30m x 30m cells. See the text for further discussion.

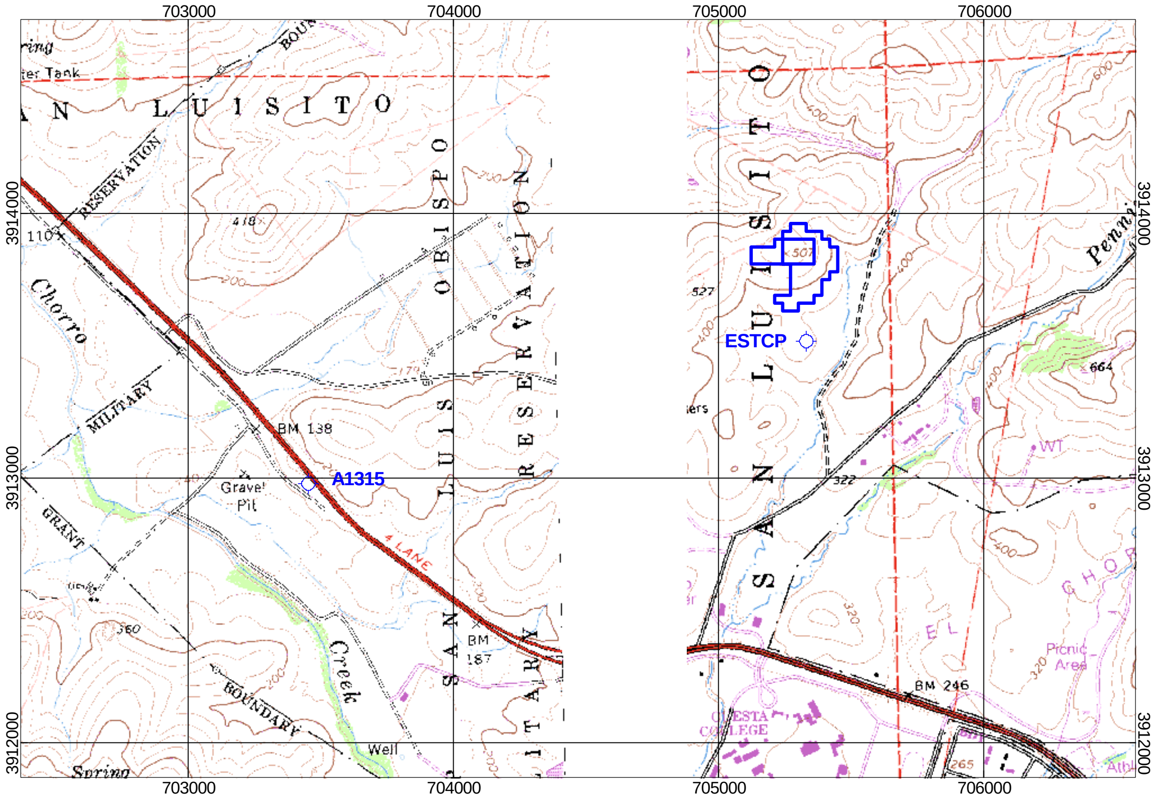


Figure 4-2 – Locations of two GPS control points with respect to Former Camp SLO demonstration site

4.6 SITE CONFIGURATION

The demonstration site was configured as a single 11.8 acre area as shown in Figure 4-1. The site spans a significant fraction of the hillside that is the historical mortar target. The test pit was located near the logistics base and the calibration strip was located outside the inner fence line, convenient to the site access road.

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The demonstration was executed in two stages. The first stage involved the response characterization of the magnetometer and EM61 MkII sensor arrays with respect to the items of interest and to the site specific geology. From this effort and the methodology described in Section 6.1, a detection threshold was established for each sensor system. In the Former Camp Sibert demonstration, a single munitions type was present. Pit measurements at various depths and orientations of an example article were made and bounding response curves generated for the 4.2-in mortar, the munitions of interest. The anomaly detection threshold was then set based on the least-favorably predicted response at the USACE standard 11x depth. For our recent GEMTADS demonstration at F.E. Warren AFB, two primary munitions types were present, 37

and 75mm projectiles. In this case, response curves were generated for each munitions type and the smaller of the two indicated detection thresholds was selected as the overall threshold. At the Former Camp SLO site, several items of interest were known to be present. A set of pit measurements were made for each of the four items of interest. The smallest appropriate least-favorable response was used to determine the final detection threshold for each data set at the depth of interest. The depth of interest for each item was initially at 45 cm by the Program Office and the Advisory Group based on the results of the 50’x50’ grid excavations to incorporate a 50% safety factor. Additionally a 50% amplitude safety factor was to be applied. After inspection of the collected data, a revised safety factor was derived for each system as discussed in Sections 5.5.6 and 5.5.9. The dynamic background level at the demonstration site was characterized for each sensor system prior to anomaly selection.

The second stage of the demonstration was the collection of survey mode data with both sensor systems over the entire demonstration site. When data collection was complete, anomalies (threshold exceedances) were detected in a manner similar to that used for the ESTCP UXO Discrimination Study at the Former Camp Sibert [7], as described in Section 6.3. A data segment around each anomaly center was extracted and analyzed using UX-Analyze, as described in Section 6.4, to fit the data to a dipole model and extract the associated fit parameters (*e.g.* position, depth, and equivalent size for the magnetometer system).

The schedule of field testing activities is provided in Figure 5-1 as a Gantt chart.

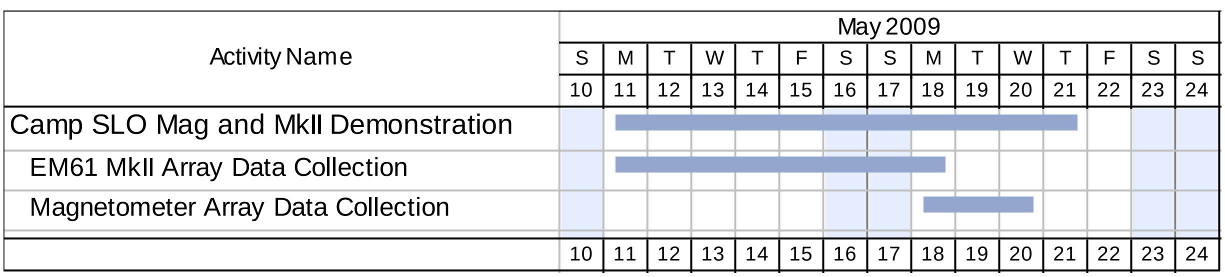


Figure 5-1 – Schedule of Field Testing Activities

5.2 SITE PREPARATION

Prior to the start of the surveys, the site was seeded with approximately 200 items of interest under the guidance of the Program Office Seeding Plan. A calibration strip containing two of each item of interest and two ferrous metal spheres was installed near the demonstration site and the site logistics location. Three GPS control points were available on site. Basic facilities such as portable toilets, storage container, and generators for power were not available on site and were mobilized in prior to the start of the Study.

5.3 SYSTEMS SPECIFICATION

This demonstration was conducted using the NRL MTADS tow vehicle and subsystems. The tow vehicle and each subsystem are described further in the following sections.

5.3.1 MTADS Tow Vehicle

The MTADS has been developed by the NRL Chemistry Division with support from ESTCP. The MTADS hardware consists of a low-magnetic-signature vehicle that is used to tow the different sensor arrays over large areas (10 - 25 acres / day) to detect buried UXO. The MTADS tow vehicle and magnetometer array at the former Camp SLO demonstration site are shown in Figure 5-2.

Figure 5-2 - MTADS tow vehicle and magnetometer array.

5.3.2 Magnetometer Array

The MTADS magnetometer array is a linear array of eight Cs-vapor magnetometer sensors (Geometrics, Inc., G-822ROV/A). The sensors are sampled at 50 Hz and typical surveys are conducted at 6 mph. This results in a sampling density of ~6 cm down track with a cross track sensor spacing of 25 cm. The sensors are nominally mounted 30 cm above the ground. The sensor boom is designed to move up to protect the sensors from damage due to impact with obstructions. This degree of freedom allows some variation in sensor height due to surface roughness. Each magnetometer measures the local magnetic field of the earth at the sensor.

For typical MTADS deployments, a single GPS antenna placed directly above the center of the sensor array is used to measure the sensor positions in real-time (5 Hz). For this demonstration, a pair of GPS antennae were mounted above the magnetometers in a manner similar to that used on the AMTADS platform [16] to provide array yaw and roll information. All navigation and sensor data are time-stamped with Universal Coordinated Time (UTC) derived from the satellite clocks and recorded by the data acquisition computer (DAQ) in the tow vehicle. The DAQ runs the MagLogNT software package (v2.921b, Geometrics, Inc.) and the data streams from each device are recorded in separate files with a common root filename. The sensor, position, and timing files are downloaded periodically throughout a survey onto magnetic disks and transferred to the data analyst for QC / analysis. Refer to Appendix C, Section C.1 for file format information.

5.3.3 EM61 MkII Array

The EM61 MkII MTADS array is an overlapping array of three pulsed-induction sensors specially modified by Geonics, Ltd. based on their EM61 MkII sensor with 1m x 1m sensor coils. The array configuration is shown schematically in Figure 5-3. The direction of travel for the array is indicated by the black arrows. Sensors #1 (Red) and #3 (Blue) are mounted side by side on the trailer while Sensor #2 (Green) is mounted 8 cm above and 10 cm aft of the other two sensors. Each EM61 MkII sensor is composed of a bottom coil and a top coil separate by fiberglass standoffs. The nominal ride height of the bottom coils is 33.5 cm above the ground and the top coil is mounted 43.5 cm above the bottom coil (bottom of coil to bottom of coil separation). The bottom coil is 5.5 cm tall and the top coil is 2.5 cm tall.

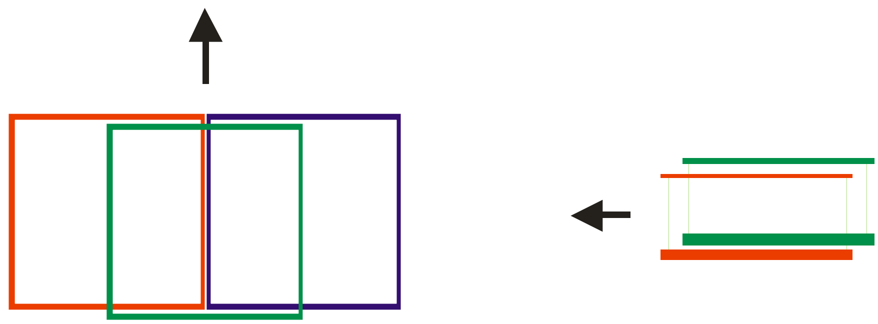


Figure 5-3 – Top and Side schematic views of the MTADS EM61 MkII array.

The EM61 MkII sensors employed by MTADS have been modified to make them more compatible with vehicular survey speeds and to increase their sensitivity to small objects. The array is operated with the three transmitters synchronized to generate the largest transmit moment. The sensor repetition rate is 125 Hz, corresponding to a period of 8 ms. The transmit pulse is approximately 2.9 ms long, approximately 250 A·m^2, and turns off in approximately 50 μs [21]. The EM61 MkII sensor can be operated in one of two modes: 1) in 4-channel ("4") mode, in which 4 time gate measurements are made for the bottom coil or 2) in Differential ("D") mode, in which 3 time gate measurements are made for the bottom coil, and one is made for the top coil. The timing of the time gates in the MTADS EM61 MkII sensors has been altered from the standard unit and the delay times are given in Table 5-1.

Table 5-1 – NRL EM61 MkII Array Gate Timing Parameters

4-Channel Mode (Bottom Coil)	Delay (μs)	Differential Mode	Delay (μs)
Gate 1	307	Bottom Gate 1	307
Gate 2	508	Top Gate 1	307
Gate 3	738	Bottom Gate 3	738
Gate 4	1000	Bottom Gate 4	1000

The notation S1 for time gate 1 and so forth is used in the remainder of this document. MTADS surveys have typically been performed using the Differential mode. As a consensus decision between the Program Office and all of the demonstrators involved in the UXO Classification Study, the 4-channel mode was used for this demonstration. While the output data packet format is identical to that of the standard MkII instrument as given in the Geonics EM61 MkII manual [3], there are some important differences in the interpretation. First, as mentioned above, the time gate delay times have been altered. Second, the byte order for the time gate Scale Factors is gates 1,4,3,2 rather than the typical 1,2,3,4. The data channels are also presented in the order gates 1,2,3,4 for 4-gate mode, or gates 1,D,3,4 for differential mode. All conversions from raw counts to response in mV are given as:

$$RESPONSE = \frac{DATA\ x\ 4.8333}{RANGE}$$

The channel-specific *RANGE* values are 100, 10, or 1, as indicated in the Scale Factor parameter in the raw data packet (see Appendix C, Section C.2). Nominal survey speed is 3 mph and the sensor readings are recorded at 10 Hz. This results in a down-track sampling of ~15 cm and a cross-track interval of 50 cm. In order to obtain sufficient "looks" at the anomalies, or to insure illumination of all three principle axes of the anomaly with the primary field, data are collected in two orthogonal surveys. The EM61 MkII array being pulled by the MTADS tow vehicle is shown in Figure 5-4.

Individual sensors in the EM61 MkII array are located using a three-receiver RTK GPS system shown schematically in Figure 5-5 [22]. The three-receiver configuration extends the concept of RTK operations from that of a fixed base station and a moving rover to moving base stations and moving rovers. The lead GPS antenna (and receiver, MB1) receive corrections from the fixed base station at 1 Hz in the same manner as for the magnetometer MTADS. This corrected position is reported at 10-20 Hz using a vendor-specific National Marine Electronics Association (NMEA) NMEA-0183 message format (PTNL,GGK or GGK). The MB1 receiver also operates as a 'moving base,' transmitting corrections (by serial cable) to the next GPS receiver (MB2) which uses the corrections to operate in RTK mode.

Figure 5-4 – MTADS EM61 MkII array pulled by the MTADS tow vehicle.

A vector (AVR1, heading (yaw), angle (pitch), and range) between the two antennae is reported at 10 Hz using a vendor-specific NMEA-0183 message format (PTNL,AVR or AVR). MB2 also provides 'moving base' corrections to the third GPS antenna (MR) and a second vector (AVR2) is reported at 10 Hz. All GPS measurements are recorded at full RTK precision, ~2-5 cm. All sensor readings are referenced to the GPS 1-PPS output to fully take advantage of the precision of the GPS measurements. An Inertial Measurement Unit (IMU) is also included on the sensor array to provide complementary platform orientation information. The IMU is a Crossbow VG300 running at 30 Hz.

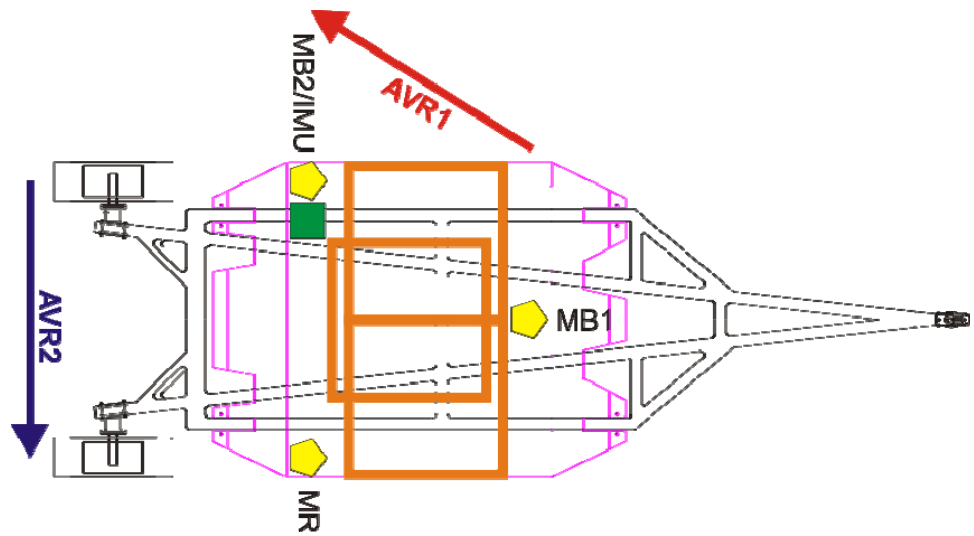


Figure 5-5 – MTADS EM trailer with approximate locations of GPS and IMU equipment indicated. The orange squares represent the EM61 MkII sensors.

A close-up view of the sensor platform is shown in Figure 5-6 which shows the three GPS antennae and the IMU (black box under the aft port GPS antenna). The airborne adjunct of the MTADS, the AMTADS uses a similar configuration with two GPS antennae / receivers to provide the yaw and roll angles of the sensor boom and pitch from the IMU [16].

Figure 5-6 – Close-up of MTADS EM61 array with GPS and IMU.

The individual data streams (sensor readings, GPS positions, times, etc.) are collected by the data acquisition computer, running the MagLogNT software package, and are each recorded in a separate file. These individual data files, which share a root name, consist of three EM61 MkII sensor data files, four GPS files (one containing the GGK and the first AVR sentences, another containing the second AVR sentence, a third containing the UTC time tag, and the fourth containing the computer time-stamped arrival of the GPS 1-PPS), and one IMU file. The EM61 MkII and IMU data files are recorded in packed binary formats. All GPS files are ASCII format. All these files are transferred to the data analyst using magnetic disks. Refer to Appendix C, Section C.2 for the details of the file formats.

5.3.4 Pilot Guidance System

The GPS positioning information used for data collection is shared with an onboard navigation guidance display and provides real-time navigational information to the operator. The guidance display was originally developed for the airborne adjunct of the MTADS system (AMTADS) [16] and is installed in the vehicle and available for the operator to use. Figure 5-7 shows a screenshot of the guidance display configured for vehicular use.

An integral part of the guidance display is the ability to import a series of planned survey lines (or transects) and to guide the operator to follow these transects. In the context of this demonstration, the pilot guidance display can be used to guide the operator to the survey area and provide immediate feedback on progress and data coverage. The display provides a left-right course correction indicator, an optional altitude indicator for aircraft applications, and color-coded flight swath overlays where the current transect is displayed in red and the other transects are displayed in black for operator reference. The survey course-over-ground (COG) is plotted for the operator in real time on the display. The COG plot is color-coded based on the RTK GPS system status. When fully operational, the COG plot is color-coded green. If the system status is degraded, the COG plot color changes from green to yellow to red (based on severity) to warn the operator and allow for on-the-fly reacquisition of the affected area. Figure 5-7 shows the operator surveying line 30 of a transect plan.

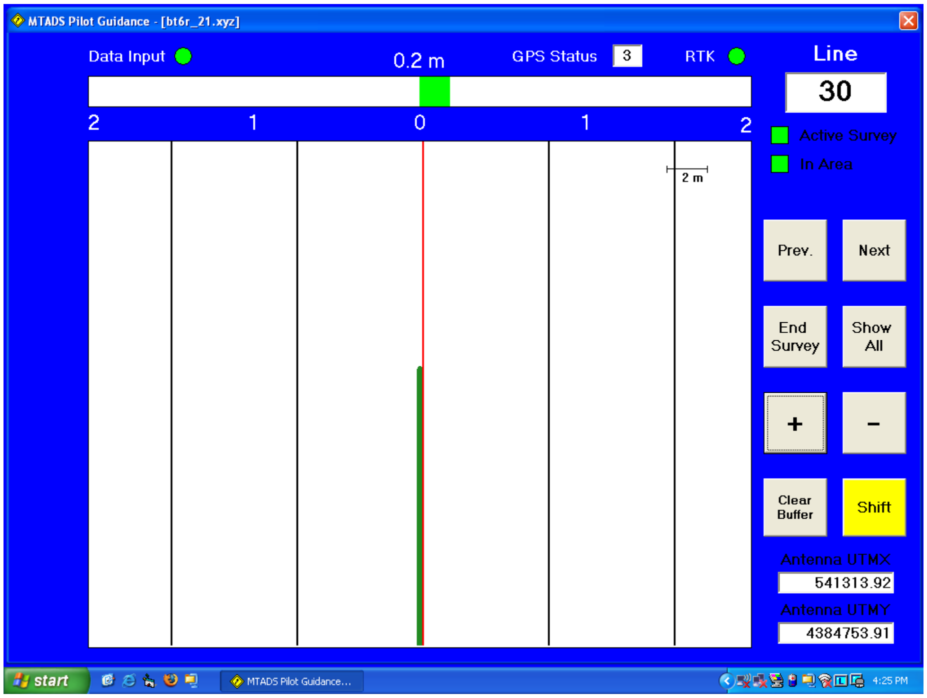


Figure 5-7 – Screenshot of MTADS Pilot Guidance display.

5.4 CALIBRATION ACTIVITIES

5.4.1 Standard MTADS Sensor Calibration

For the EM61 MkII array, the standard performance checks include three types of measurements. At the beginning of field work and again each morning quiet, static data are collected for a period (15 - 20 minutes or as directed by the Quality Assurance Office (QAO)) with all systems powered up and warmed up (typically 30 minutes after the transmitter is turned on). Next, a calibration item, a 4" diameter Aluminum (Al) sphere, is placed in a series of well-defined positions along a fiberglass rail mounted a fixed distance above the array to verify the spatial response of the array to the object. The system is stationary for this data collection. Finally, a systems timing check using a fixed-position wire or chain placed on the ground is conducted. At the discretion of the QAO, the timing check may be repeated in the middle of the survey day. At the discretion of the QAO, the timing check and the Al sphere measurements may be repeated at the end of the survey day.

For the magnetometer array, the Al sphere and timing chain measurements are not made and the quiet period is reduced to 5-10 minutes. Each sensor platform's performance check requirements are based on data rates and the historical stability and reproducibility of each sensor type.

Every effort was made to minimize the movement of personnel and equipment in the vicinity of the MTADS during these data collections. The 2-D positioning variation was evaluated by computing the standard deviation of both the northing and easting components of the position

data for the entire period and combining them as the square root of the sum of the squares. The standard deviation for the demedianed sensor data from each sensor was computed and the arithmetic mean was computed for each data set. In occasional cases, an obvious artifact was present in the data (e.g. a vehicle pulls up along side the tow vehicle unannounced) and distorts a portion of the static run. In these cases, only the unperturbed data were used. The aggregate average and standard deviation (1σ) of both the positioning and sensor data for all data sets were then computed. The results are shown in the following time-series figures. Figure 5-8 shows the combined 2-D position variation for the entire demonstration and the summary results are tabulated in Table 5-2. The source of the large variation in 2D positioning on the first day of data collection is not clear but this was the only day where the base station of another team (MSEMS) was used. Our base station was used for all other days.

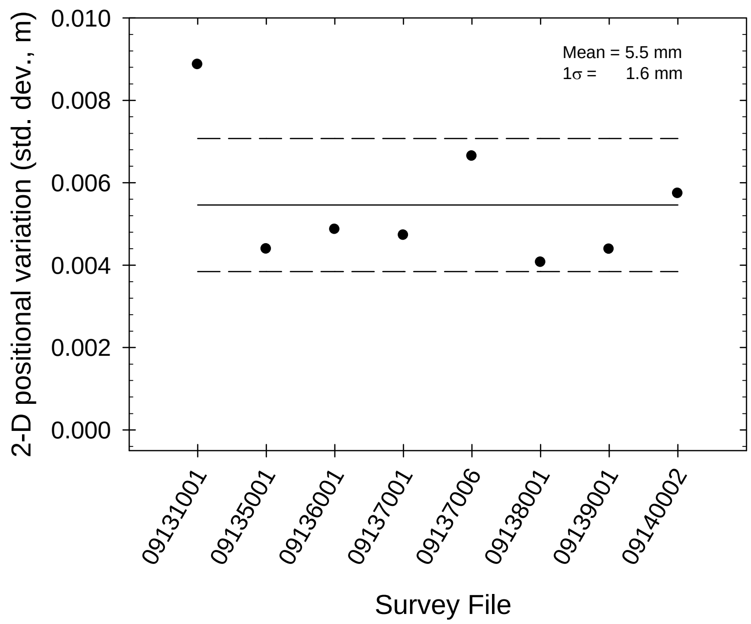


Figure 5-8 – 2-D position variation data runs for stationary data collected at the south end of the calibration strip. The horizontal axis is survey file name. The solid line represents the aggregate average positional variation and the dashed lines represent a 1σ envelope.

Table 5-2 – Stationary Position Variation Summary

Result Type	Value
2-D Position	0.55 ± 0.16 cm
3-D Position	0.91 ± 0.19 cm

Figure 5-9 and Figure 5-10 show the sensor variations from the stationary data collections broken out by sensor platform; magnetometer, and EM61 MkII respectively. Table 5-3 and Table 5-4 summarize the stationary sensor data collection results. It should be noted that each sensor platform was only deployed for a few days, so the variations are instructive taken in that context.

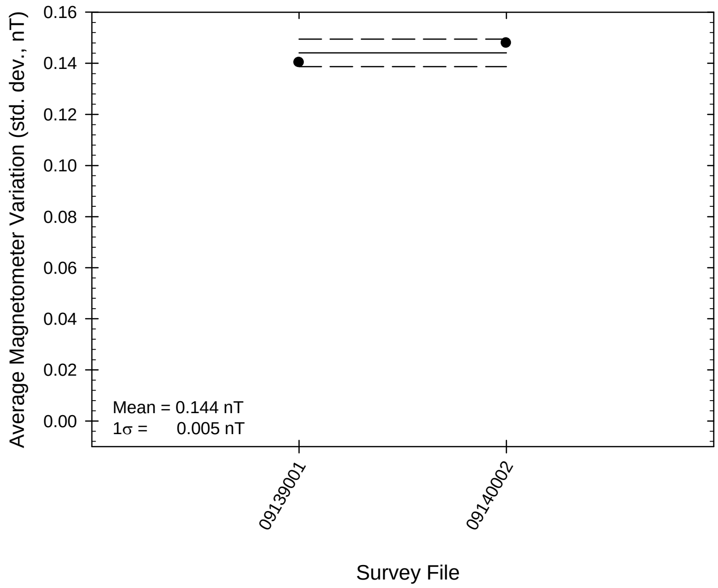


Figure 5-9 – Overall magnetometer variation data runs for static data collected at the calibration strip. The horizontal axis is survey file number. The solid line represents the aggregate average sensor variation and the dashed lines represent a 1σ envelope.

Table 5-3 – Magnetometer Array Static Test Data Results (demedianed values)

Result Type	Value
Magnetometer	0.144 ± 0.005 nT

Table 5-4 – EM61 MkII Array Static Test Data Results (demedianed values)

Result Type	Value
Gate 1	1.52 ± 0.08 mV
Gate 2	1.09 ± 0.10 mV
Gate 3	1.08 ± 0.23 mV
Gate 4	0.97 ± 0.19 mV
All Gates	1.17 ± 0.12 mV

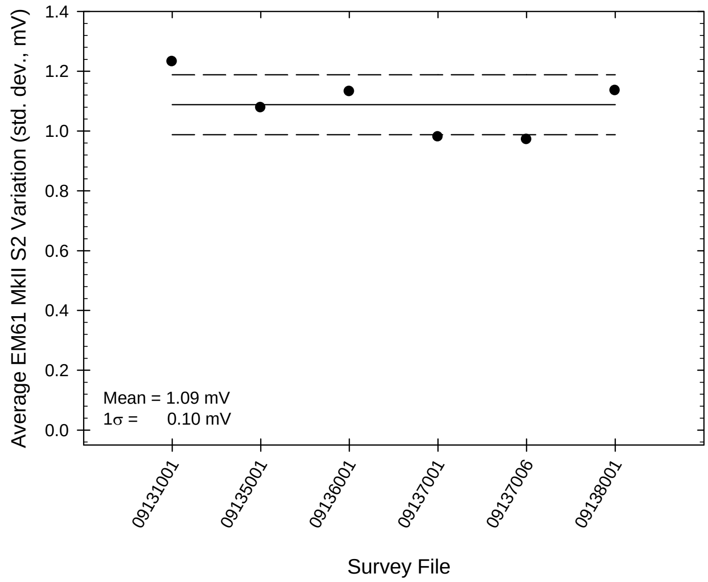


Figure 5-10 – Overall variation of MTADS EM61 MkII array, S2 time gate only for daily stationary data collection. The horizontal axis is survey file. number. The solid line represents the aggregate average sensor variation and the dashed lines represent a 1σ envelope.

5.4.2 Emplaced Sensor Calibration Items

A calibration strip comprised of two replicates of each item of interest was emplaced on site to verify proper system operation on a daily basis. The calibration strip was surveyed each morning and each evening that data were collected. The only exceptions to this were due to unexpected early shutdown for the day arising from equipment issues. The data were preprocessed, checked for data quality, and signal strengths and noise levels compared to the appropriate response curves and site-specific background levels to verify consistency of system performance. Details of the contents of the sensor calibration strip are given in Table 5-5. All items were emplaced in October, 2008 except for the two shotputs which were emplaced in April, 2009.

Figure 5-11 shows an EM61 MkII array (S2) anomaly map of the calibration strip. The midpoint positions of the emplaced items, as reported in Table 5-5, are shown as open circles. The linear feature at the northern end of the calibration strip is the response due to the timing chain that was set out for EM61 MkII array timing calibration.

After the static data collection measurements were completed each day, the calibration lane was surveyed. To insure that complete signatures for each emplaced item were recorded, a calibration lane survey was comprised of 3 parallel passes. At the end of each field day involving data collection, the calibration lane was surveyed again prior to system shutdown in the same manner. To evaluate the data from the calibration items, the peak anomaly amplitude for each emplaced item in each survey was extracted in the same manner and using the same data grid size as was used for threshold exceedance detection (See Section 6.3).

Table 5-5 – Details of Former Camp SLO Calibration Strip

Item ID	Description	Easting (m)	Northing (m)	Depth (m)	Inclination	Azimuth (° cw from N)
T-001	shotput	705,417.00	3,913,682.00	0.25	N/A	N/A
T-002	81mm	705,420.92	3,913,687.63	0.30	Vertical Down	0
T-003	81mm	705,424.10	3,913,692.95	0.30	Horizontal	120
T-004	60mm	705,427.53	3,913,698.54	0.30	Vertical Down	0
T-005	60mm	705,430.85	3,913,704.10	0.30	Horizontal	120
T-006	4.2" mortar	705,434.54	3,913,709.44	0.30	Vertical Down	0
T-007	4.2" mortar	705,437.99	3,913,715.04	0.30	Horizontal	120
T-008	2.36" rocket	705,441.46	3,913,720.24	0.30	Vertical Down	0
T-009	2.36" rocket	705,445.00	3,913,725.91	0.30	Horizontal	120
T-010	shotput	705,448.50	3,913,731.50	0.35	N/A	N/A

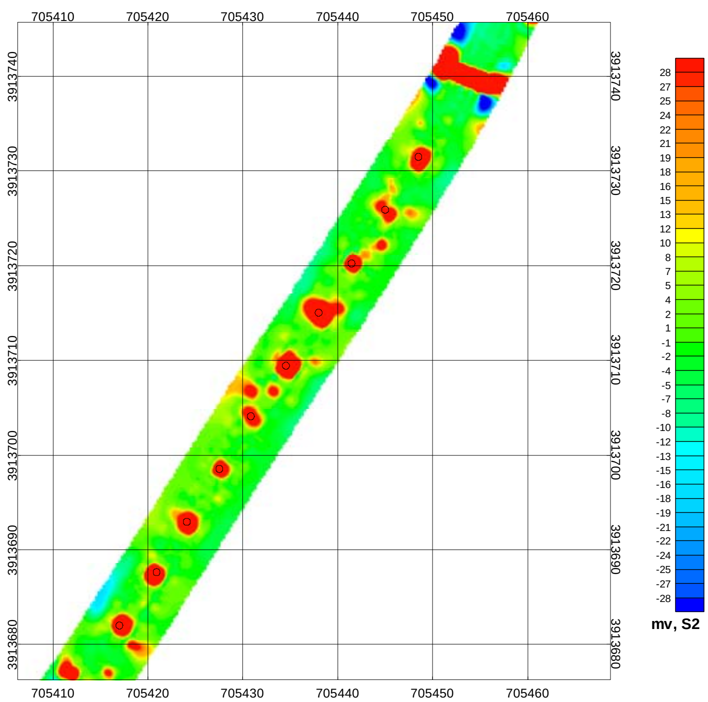


Figure 5-11 – EM61 MkII array S2 anomaly map of the emplaced calibration strip. The midpoint positions of the emplaced items are shown as open circles.

For the magnetometer data, the peak positive amplitude was used. An 8.5m x 6m sub-area immediately north of the calibration strip, identified to be relatively free of anomalies, was used

for each data set to determine the driving background level for the system on this site. The coordinates of the sub-area corners are listed in Table 5-6. The standard deviation (1σ) was then calculated for the sub-area and that value was reported as the driving background value for each calibration survey. The aggregate peak amplitude values for each survey of the calibration lane (average and standard deviation (1σ)) are tabulated in Table 5-7 and Table 5-8, for the magnetometer and the EM61 MkII arrays respectively.

Table 5-6 – Corner coordinates of the area for calculating the driving background sensor levels

Easting (UTM 10N, m)	Northing (UTM 10N, m)
705,446.48	3,913,735.23
705,453.62	3,913,730.94
705,457.13	3,913,736.27
705,449.34	3,913,740,04

Table 5-7 – Peak Positive Aggregate Demedianed Magnetometer Values for Calibration Strip Emplaced Items

Item ID	Description	Depth (m)	Avg. Signal (nT)	Std. Dev (nT, 1σ)
T-001	shotput	0.25	97.48	6.49
T-002	81mm	0.30	144.46	8.78
T-003	81mm	0.30	36.74	2.59
T-004	60mm	0.30	47.04	1.94
T-005	60mm	0.30	21.04	0.84
T-006	4.2-in mortar	0.30	671.84	40.22
T-007	4.2-in mortar	0.30	121.00	5.90
T-008	2.36-in rocket	0.30	281.42	9.17
T-009	2.36-in rocket	0.30	42.86	1.87
T-010	shotput	0.35	135.52	7.88
	driving background	N/A	1.92	0.07

Figure 5-12 and Figure 5-13 plot the peak anomaly amplitude values for the vertical 4.2-in Mortar (T-006) and the horizontal 2.36-in Rocket (T-009) for all EM61 MkII data sets in time series as examples. For the EM61 MkII array, T-006 exhibited the largest peak amplitude values. The T-009 values were approximately 1/25 those for T-006 and are approximately three times the final anomaly detection threshold chosen for the MkII array. The solid line indicates the aggregate average and the dashed lines indicate a 1σ envelope. The largest component of the variation is most likely the ability of the driver to reproducibility place the sensor array on the exact same path each and every time.

Table 5-8 – Peak Aggregate Demedianed EM61 MkII Values (S2) for Calibration Strip Emplaced Items

Item ID	Description	Depth (m)	Avg. Signal (mV, S2)	Std. Dev (mV, 1σ)
T-001	shotput	0.25	365.99	9.90
T-002	81mm	0.30	645.37	27.39
T-003	81mm	0.30	236.82	7.98
T-004	60mm	0.30	248.21	13.17
T-005	60mm	0.30	79.29	20.63
T-006	4.2-in mortar	0.30	1763.90	107.47
T-007	4.2-in mortar	0.30	759.23	48.66
T-008	2.36-in rocket	0.30	691.86	61.28
T-009	2.36-in rocket	0.30	85.59	8.58
T-010	shotput	0.35	240.35	6.59
	driving background	N/A	2.58	0.17

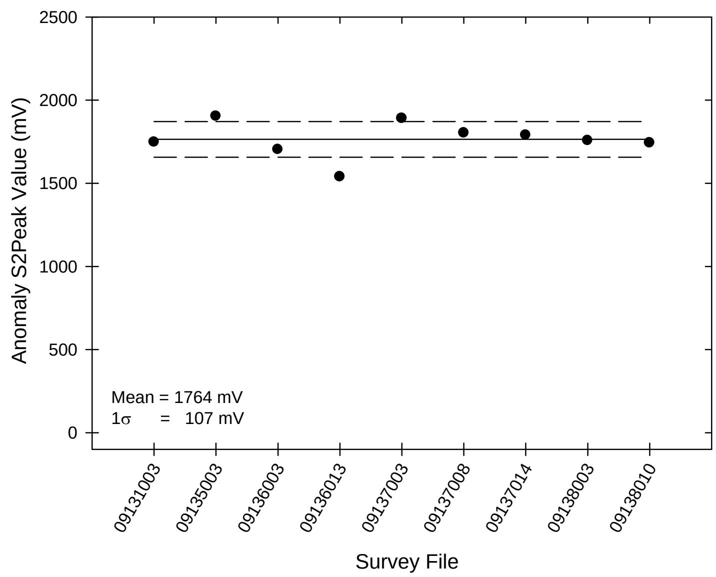


Figure 5-12 – Peak anomaly amplitude values from each EM61 MkII array calibration lane survey for the vertical 4.2-in Mortar (T-006). The solid line represents the aggregate average peak positive value and the dashed lines represent a 1σ envelope.

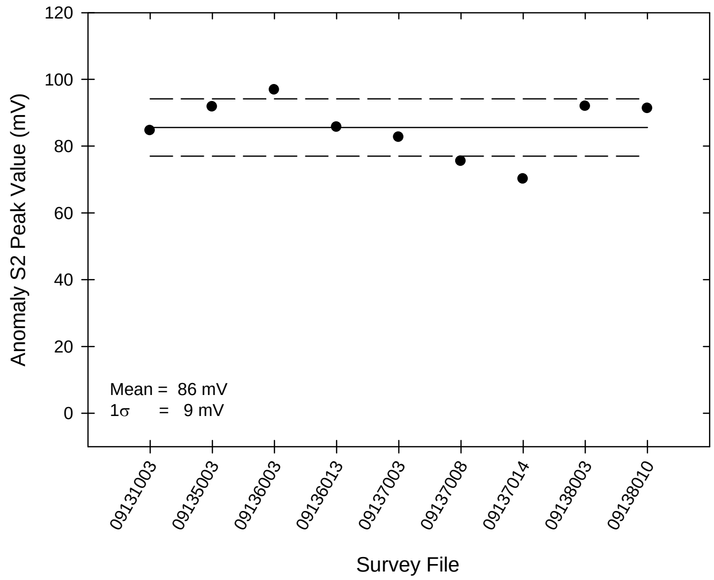


Figure 5-13 – Peak anomaly amplitude values from each EM61 MkII array calibration lane survey for the horizontal 2.36-in Rocket (T-009). The solid line represents the aggregate average peak positive value and the dashed lines represent a 1σ envelope.

5.5 DATA COLLECTION PROCEDURES

5.5.1 Scale of Demonstration

The MTADS magnetometer and EM61 MkII arrays conducted total coverage surveys of the 11.8-acre demonstration site at the Former Camp San Luis Obispo. Threshold exceedances were identified from each data set using an aggregate threshold determined from the response curves for each system and the items of interest. The measured site background levels and the depth of interest were also included in the threshold determination process. A data segment around each threshold exceedance was extracted, analyzed, and dipole model fit parameters extracted. These results were provided to the ESTCP Program Office in addition to the archival data.

5.5.2 Sample Density

Magnetometer data were collected with nominal down-track spacing of 6 cm and cross track spacing of 25 cm. EM61 MkII data were collected with nominal down-track spacing of 15 cm and cross track spacing of 50 cm. Because the three transmitters in the EM61 MkII array are synchronized, data were collected in two orthogonal directions to increase the number of “looks” or directions of illumination of each anomaly by the array. This effectively doubled the data density as well as improved site coverage around obstacles by allowing data collection to occur in two orthogonal directions.

Data density was calculated from the number of valid data points recorded within the survey area and the size of the survey area (in m^2). The resulting values are given in Table 5-9. The data density for the MTADS magnetometer system is 5.7 times higher than the EM systems. The MTADS magnetometer system records data at 50 Hz (as compared to approximately 10 Hz for the EM systems) and typically drives at twice the speed of the EM systems. The magnetometer array has 8 sensors while the EM sensors have effectively 6 sensors once the orthogonal survey pattern used is considered. Multiplying all of these factors together combines to a factor of 3.3. Due to the terrain and upgraded tow vehicle transmission, the magnetometer array survey was conducted at a speed closer to the EM61 MkII array survey, furthering increasing the magnetometer data density.

Table 5-9 – Resultant Data Density by Sensor System

		Data Density (pts/m^2)	
Survey Area	**Area (m^2)**	**Magnetometer**	**EM61 MkII**
Site	47,700	131	23

5.5.3 Quality Checks

Preventative maintenance inspections were conducted at least once a day by all team members, focusing particularly on the tow vehicle and sensor trailer. Any deficiencies were addressed according to the severity of the deficiency. Parts, tools, and materials for many maintenance scenarios are available in the system spares inventory which was on site. Local vendors were utilized for scenarios that could not be resolved onsite. Status on any break-downs / failures which resulted in long-term delays in operations were immediately reported to the ESTCP Program Office.

For the magnetometer array, the following data quality checks and procedures were used to insure a quality data product. MTADS magnetometer survey raw data generally falls into two categories, location and magnetometer sensor measurements. The data set has eleven separate files, each containing the data from a single system device. Each device has a unique data rate. For each file, the number of entries to the product (total survey time * data rate) were compared. Any discrepancies were flagged for the data analyst to address.

For magnetometer sensor data, operational values are typically on the order of 50,000 nT and have noise levels of ~0.5 nT peak-to-peak (PP) static and 3-5 nT PP in motion. Sensor "drop-outs" can occur if the sensor is tilted out of the operation zone with respect to the earth's magnetic field. If a sensor cable is severed or damaged while in motion, the sensor output value will drop below 20,000 nT and/or become very noisy (1,000's of nT PP). All magnetometer sensor channels (8 total) were examined in each survey file set for these conditions and any data which were deemed unsatisfactory were flagged and not processed further.

For location data, the RTK GPS receivers present a Fix Quality value that relates to the quality / precision of the reported position. A Fix Quality (FQ) value of 3 (RTK Fixed) is the best accuracy (typically 3-5 cm or better). A FQ value of 2 (RTK Float) indicates that the highest

level of RTK has not be reached yet and location accuracy can be degraded to as poor as ~1 m. FQs 1 & 4 correspond to the Autonomous and DGPS operational modes, respectively. Data collected under FQ 3 and FQ 2 (at the discretion of the data analyst) were retained. Any other data were deemed unsatisfactory, flagged, and not processed further. The section of data containing the flagged data was logged for future re-acquisition as required. Data which meet these standards are of the quality typical of the MTADS system.

For the EM61 MkII array, similar procedures were used, differing only in the specific details of the data collected.

5.5.4 Data Handling

Data were stored electronically as collected on the MTADS vehicle data acquisition computer hard drives. Approximately every two survey hours, the collected data were copied onto removable media and transferred to the data analyst for QC/analysis. The data were moved onto the data analyst's computer and the media recycled. Raw data and analysis results were backed up from the data analyst's computer to optical media (CD-R or DVD-R) or external hard disks daily. These results were archived on an internal file server at NRL or SAIC at the end of the survey. Refer to Appendix C for specific details on the file formats. All field notes / activity logs were written in ink and stored in archival laboratory notebooks. These notebooks are archived at NRL or SAIC. Relevant sections are reproduced in demonstration reports such as this document. Dr. Daniel Steinhurst is the POC for obtaining data and other information. His contact information is provided in Appendix B of this report.

5.5.5 EM61 MkII Survey Data Summary

The EM61 MkII portion of the demonstration was conducted starting on Monday, May 11th, 2009 and was completed on Monday, May 18th, 2009. Field operations stopped during the afternoon of May 11th due to a failure of the tow vehicle transmission. A new transmission was procured and installed and field operations resumed on Friday, May 15th, 2009. The site was surveyed completely once using a primary direction appropriate for each subsection of the site to maximize the covered area. A subsequent survey direction was then selected for each subsection to provide the orthogonal survey direction and to fill in around any obstacles that disrupted data collection in the primary direction. The calibration strip was typically surveyed twice daily. One of the EM61 MkII electronics consoles failed on Sunday, May 17th, 2009. The unit was replaced and the daily calibration routine repeated to verify the operation status of the spare console. An anomaly map of all data EM61 MkII data (both directions) for the demonstration site is shown in Figure 5-14.

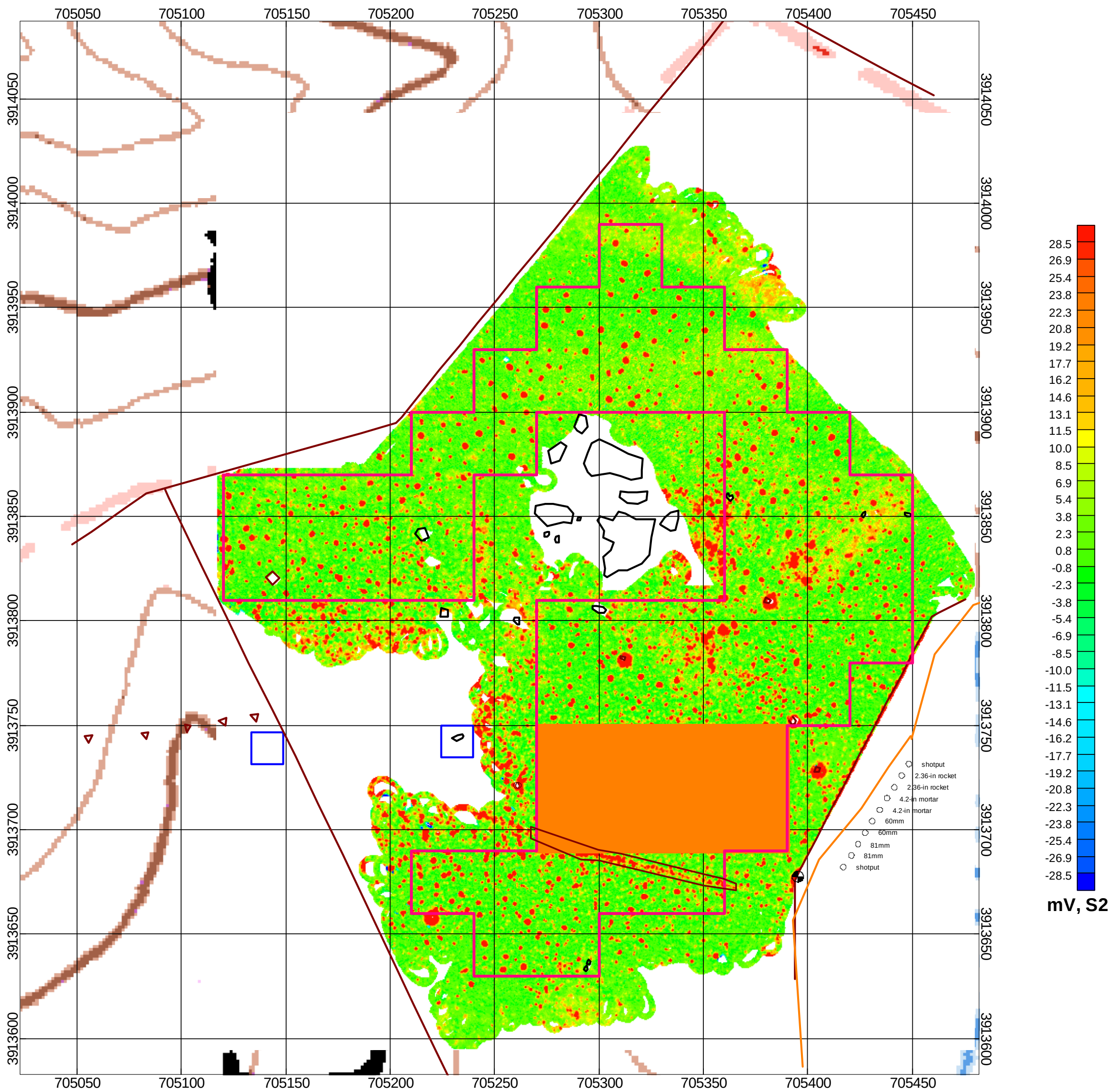


Figure 5-14 – MTADS EM61 MkII array anomaly map (mV, S2) for the former Camp SLO demonstration site. The orange-shaded block represents the Vehicular Area. The boundary of a path leading through the southern part of the site is indicted with a black boundary.

5.5.6 EM61 MkII Response Curves

The munitions of interest for this demonstration site are the 60mm, 81mm, and 4.2-in Mortars and the 2.36-in Rocket. The demonstration site was seeded with approximately 200 of these items as blind tests for the data collection efforts and to provide sufficient true positives in the collected data sets for the data processing efforts. Prior to deployment to the former Camp SLO

demonstration site, a series of test-pit measurements were made at our Blossom Point facility in the manner described in Section 6.1. An example of each of the four munitions types was acquired from ATC and the USACE. Figure 5-15 through Figure 5-18 show both the measured peak response (S2) for each item (open diamonds) and the dipole-model maximum (red) and minimum (blue) bounding curves for each item for the EM61 MkII array. The second time gate was selected for the EM61 MkII array, operating in ‘4-channel’ mode, based on the relative numbers of anomalies selected for each of the four available time gates at the depth of interest. The first time gate was more susceptible to drift and geology than the other three and the minimum responses for the third and fourth time gates were too close to their background signal levels for robust threshold exceedance extraction. For the magnetometer array data, the peak positive response was used. The RMS background level for several ‘quiet’ patches of EM61 MkII data within the demonstration site were determined and averaged to get a measure of the overall site background level. The average value was found to be 3.46 mV, S2. The average RMS background signal level (1σ) for the quiet area at the north end of the calibration strip (See Section 5.4.2) was determined to be 2.58 mV, S2. The site background level is shown as a horizontal line (dash-double dot) in the figures. Two scenarios were investigated for choosing appropriate depth of interest and amplitude safety factors. Applying a 50% safety factor to the depth of interest (30 cm from the 50’x50’ grid digging results) to 45cm yielded slightly lower thresholds (29 mV, S2 for the 60mm Mortar) than did a 50% amplitude safety factor at 30 cm. The more conservative 45 cm depth of interest scenario was chosen. The depth of interest, 45 cm, is indicated as a vertical line (dashed). The minimum bounding values for each munitions type at the depth of interest are summarized in Table 5-10. The minimum response for the 60mm Mortar at the depth of interest, 45 cm, was the minimum bounding response at 29 mV, S2.

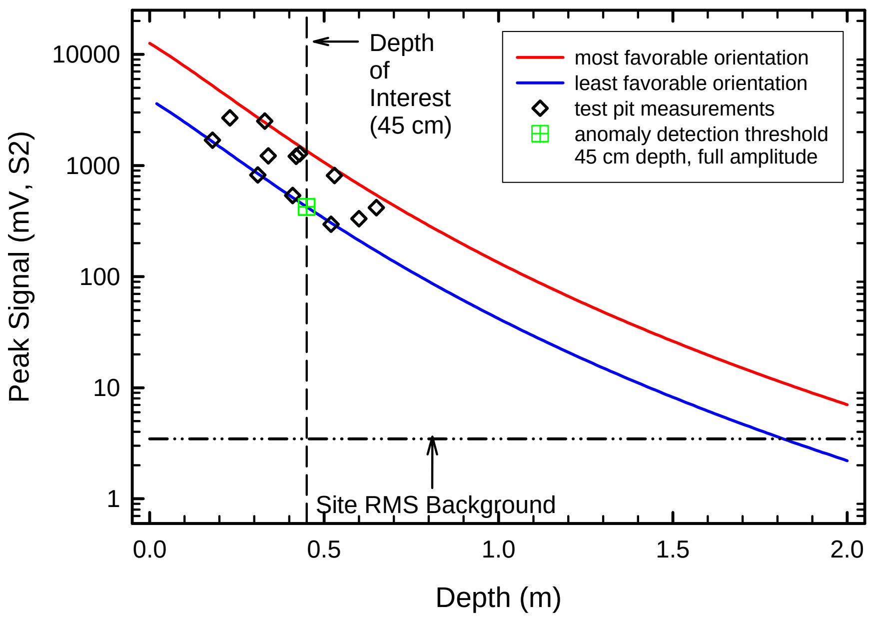


Figure 5-15 – MTADS EM61 MkII array / 4.2-in Mortar S2 response curve. The colored lines represent the maximum (red) and minimum (blue) predicted response for the system-item pairing as a function of depth. Test pit measurements are shown as open black diamonds. The minimum response at the depth of interest is shown as a green square and the site RMS background level is shown as a black line (dash – double dot).

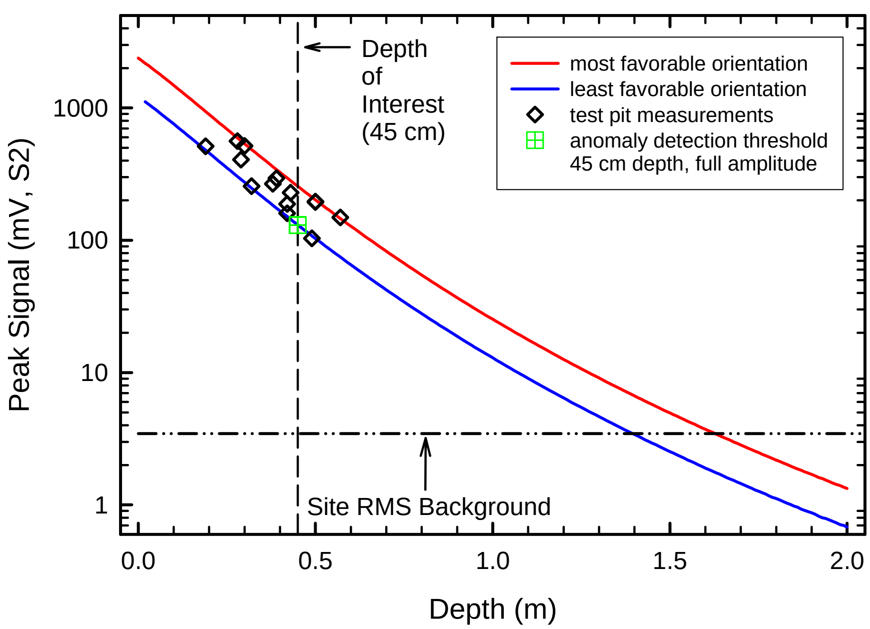


Figure 5-16 – MTADS EM61 MkII array / 81mm Mortar S2 response curve. The colored lines represent the maximum (red) and minimum (blue) predicted response for the system-item pairing as a function of depth. Test pit measurements are shown as open black diamonds. The minimum response at the depth of interest is shown as a green square and the site RMS background level is shown as a black line (dash – double dot).

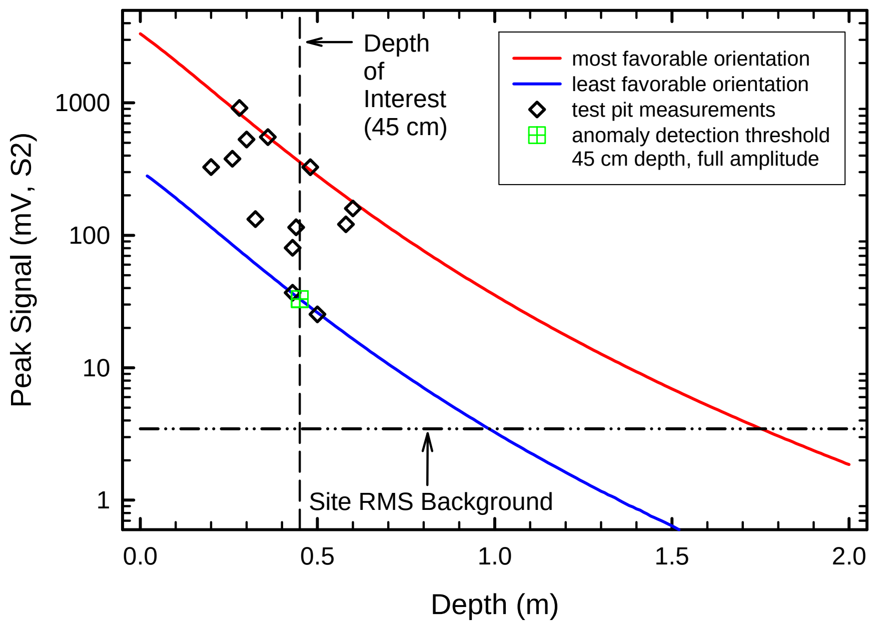


Figure 5-17 – MTADS EM61 MkII array / 2.36-in Rocket S2 response curve. The colored lines represent the maximum (red) and minimum (blue) predicted response for the system-item pairing as a function of depth. Test pit measurements are shown as open black diamonds. The minimum response at the depth of interest is shown as a green square and the site RMS background level is shown as a black line (dash – double dot).

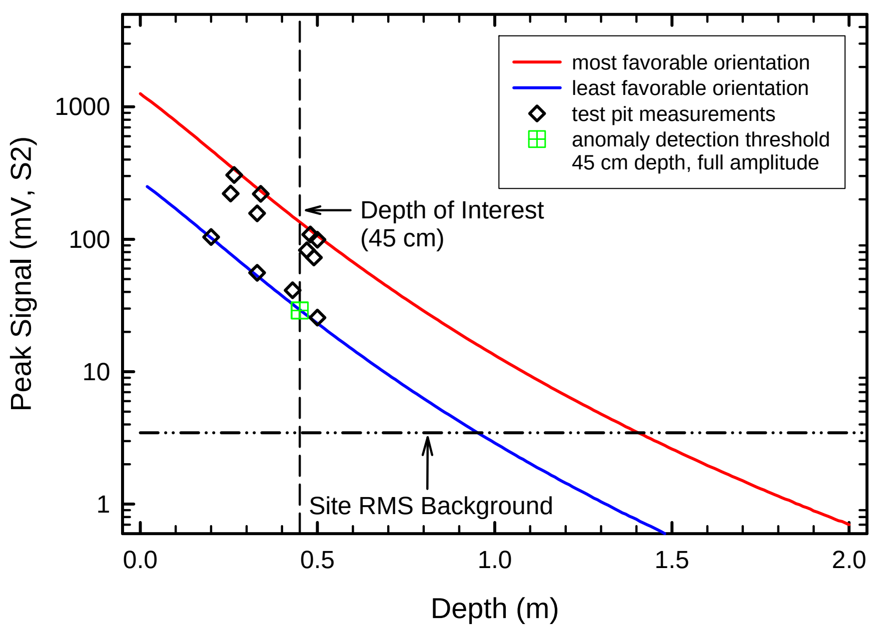


Figure 5-18 – MTADS EM61 MkII array / 60mm Mortar S2 response curve. The colored lines represent the maximum (red) and minimum (blue) predicted response for the system-item pairing as a function of depth. Test pit measurements are shown as open black diamonds. The minimum response at the depth of interest is shown as a green square and the site RMS background level is shown as a black line (dash – double dot).

Table 5-10 – MTADS EM61 MkII Array Minimum Response Values by Munitions Type at a Depth of 45 cm

Description	MkII (S2, mV)
60mm	29
81mm	131
2.36-in rocket	33
4.2-in mortar	424

5.5.7 EM61 MkII Survey Data

Based on the test pit data and the response curves, a collective threshold of 29 mV, S2 was established. At this threshold, 1813 threshold exceedances were extracted from the EM61 MkII array data set for the demonstration site. Threshold exceedances located in the 'Vehicular Area" and within the boundary of the path which leads through the southern part of the site (see Figure 5-14 caption) were excluded after discussion with the Program Office. A data segment around each threshold exceedance was extracted and analyzed using the UX-Analyze subsystem of Oasis montaj software package as described in Section 6.4 to fit the data to a dipole model and extract the associated fit parameters (position, depth, principle axis polarizabilities, orientation, and equivalent size) in an unattended batch mode. Due to the limitations of the UX-Analyze subsystem regarding EM61 MkII array data, only one time gate could be used in the analysis. The same time gate used to extract the threshold exceedance, S2, was used for the fitting process. These results were then given to an experienced data analyst to review each anomaly individually.

As the data analyst reviewed each threshold exceedance, the following conditions were considered: 1) Was the fit coherence high enough (fit good enough)? Typically a fit coherence of 0.85 or greater was considered acceptable. For those fits that scored less than 0.85, "Poor Fit." was noted in the comment field of the anomaly list. 2) Did the model fit resemble the original data under visual inspection? If not, "Poor Fit." was noted in the comment field, in some cases in contradiction to 1). 3) If the fit routine did not converge, "No Fit. Fit did not converge" was noted in the comment field. The fit parameters listed in the anomaly list are not to be trusted. 4) If part of the anomaly signature was missing (e.g. because of a rock in the way), "Partial Signature" was noted in the comment field. 5) If one or more threshold exceedances appeared to be part of the same compact anomaly, the involved exceedances were noted in the comment field of each involved anomaly with a notation of the form "Anomalies XXX/YYY/ZZZ." These exceedances had their fit boundaries adjusted to include the data from all associated exceedances such that each exceedance would return the same fit results (approximately). 6) If one or more threshold exceedances appeared to be part of a large, overlapping structure, it was noted in the comment field with "Extended Target XXX/YYY/ZZZ." The data analyst made a best attempt to assign appropriate fit boundaries to each exceedance.

The EM61 MkII data sets are provided on the attached DVD in two forms, a complete combined data set and two separate data sets, one for each survey direction). The anomaly fit parameter results are also provided on the attached DVD as an Excel spreadsheet.

5.5.8 Magnetometer Survey Data Summary

The magnetometer portion of the demonstration was conducted starting on Monday, May 18th, 2009 and was completed on Wednesday, May 20th, 2009. The site was surveyed completely once using a primary direction appropriate for each subsection of the site to maximize the covered area. The calibration strip was typically surveyed twice daily. An anomaly map of the magnetometer data for the demonstration site is shown in Figure 5-19.

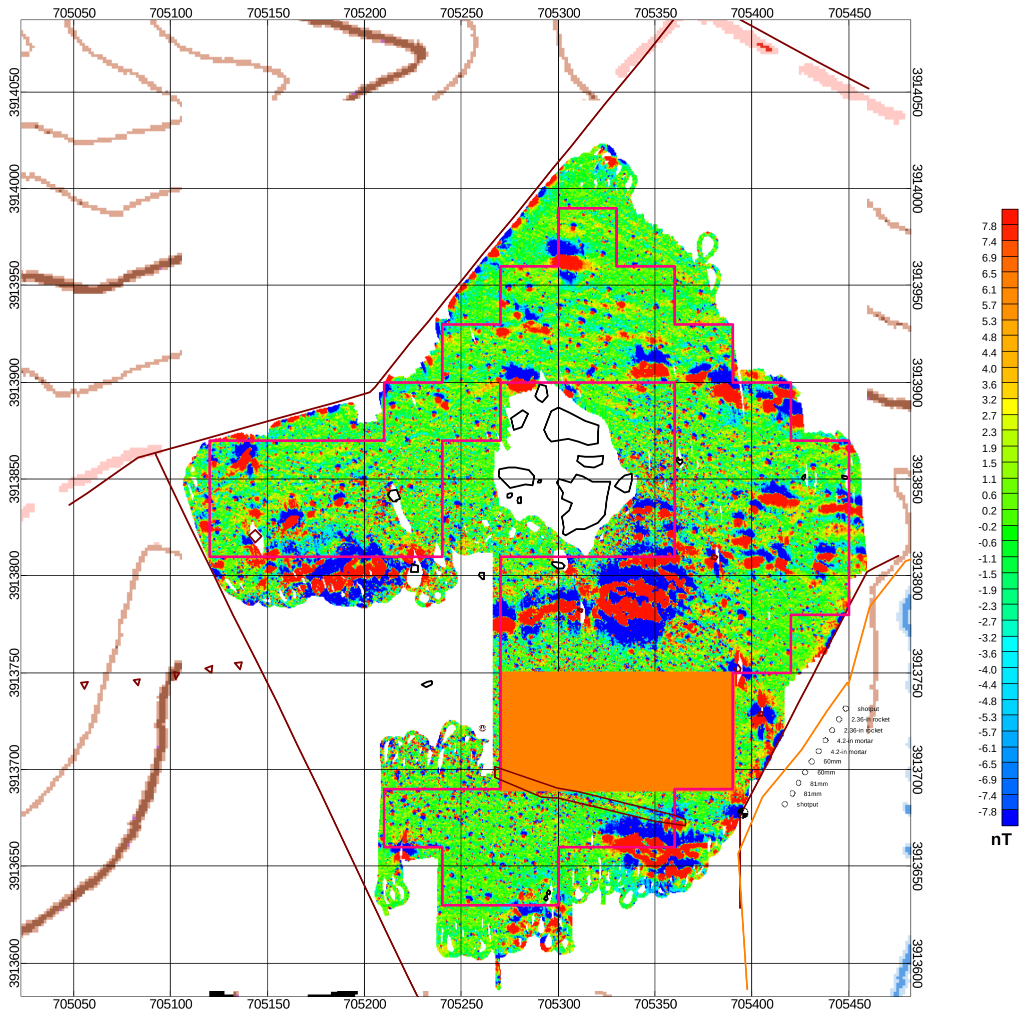


Figure 5-19 – MTADS magnetometer array anomaly map (nT) for the former Camp SLO demonstration site. The orange-shaded block represents the Vehicular Area. The boundary of a path leading through the southern part of the site is indicted with a black boundary.

5.5.9 Magnetometer Response Curves

As was discussed in Section 5.5.6 for the EM61 MkII Array, prior to deployment to the former Camp SLO demonstration site, a series of test-pit measurements were made at Blossom Point in

the manner described in Section 6.1. An example of each of the four munitions types was acquired from ATC and the USACoE. Figure 5-20 through Figure 5-23 show both the measured peak response (nT) for each item (open diamonds) and the dipole-model maximum (red) and minimum (blue) response bounding curves for each item for the magnetometer array. For the 60- and 81-mm Mortars, additional pit data were available from a previous study and was included as well. For the magnetometer array data, the peak positive response was used. Additionally, the Earth's magnetic field has a different amplitude and orientation at our Blossom Point site than it does at the former Camp SLO demonstration site. The details are given in Table 5-11. The model-predicated response is a function of location and the appropriate response curves are used throughout this document as required. The average RMS background signal level (1σ) for the quiet area at the north end of the calibration strip (See Section 5.4.2) was determined to be 1.92 nT. The background level is shown as a horizontal line (dash-double dot) in the figures. The depth of interest, 30 cm, is indicated as a vertical line (dashed). The minimum bounding value for each munitions and each sensor system at the depth of interest are summarized in Table 5-12. Two scenarios were investigated for choosing appropriate depth of interest and amplitude safety factors. Applying a 50% safety factor to the depth of interest (30 cm from the 50'x50' grid digging results) to 45cm yielded slightly higher thresholds (8.8 nT for the 60mm Mortar) than did a 50% amplitude safety factor at 30 cm (8.2 nT). The more conservative 50% amplitude safety factor scenario was chosen. The minimum response for the 60mm Mortar at the depth of interest, 30 cm, was the minimum bounding response at 16.4 nT. An amplitude safety factor of 50% was applied, resulting in a final threshold value of 8.2 nT.

Table 5-11 – Site-specific parameters of the Earth's magnetic field

Blossom Point, MD	**Latitude (NAD83, deg)**	**Longitude (deg) (NAD83, deg)**	**Elevation (m)**
	38º 25' 1.21759" N	77º 6' 10.31694" W	6.358
	Avg. Amplitude(nT)[a]	**Inclination (deg)**	**Declination (deg)**
	51,960.57	66.11	-10.54
Former Camp SLO	**Latitude (NAD83, deg)**	**Longitude (deg) (NAD83, deg)**	**Elevation (m)**
	35º 20' 37.77465" N	120º 44' 25.95073" W	113.69
	Avg. Amplitude(nT)	**Inclination (deg)**	**Declination (deg)**
	47,996.50	59.53	13.59

[a] Values calculated for 06/01/2009.

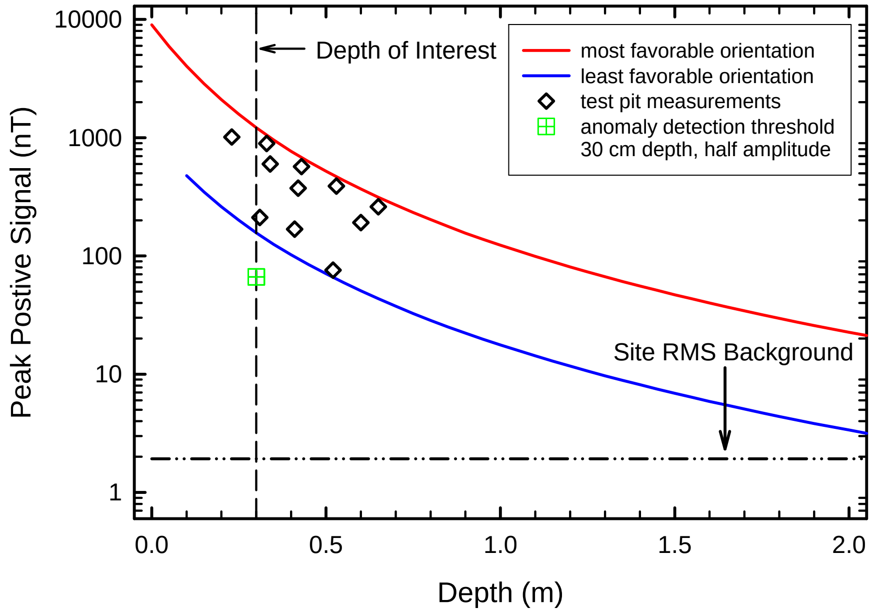


Figure 5-20 – MTADS Magnetometer array / 4.2-in Mortar response curve. The colored line represents the maximum (red) and minimum (blue) predicted responses for the system-item pairing as a function of depth. Test pit measurements are shown as open black diamonds. The minimum response at the depth of interest is shown as a green square and the site RMS background level is shown as a black line (dash – double dot).

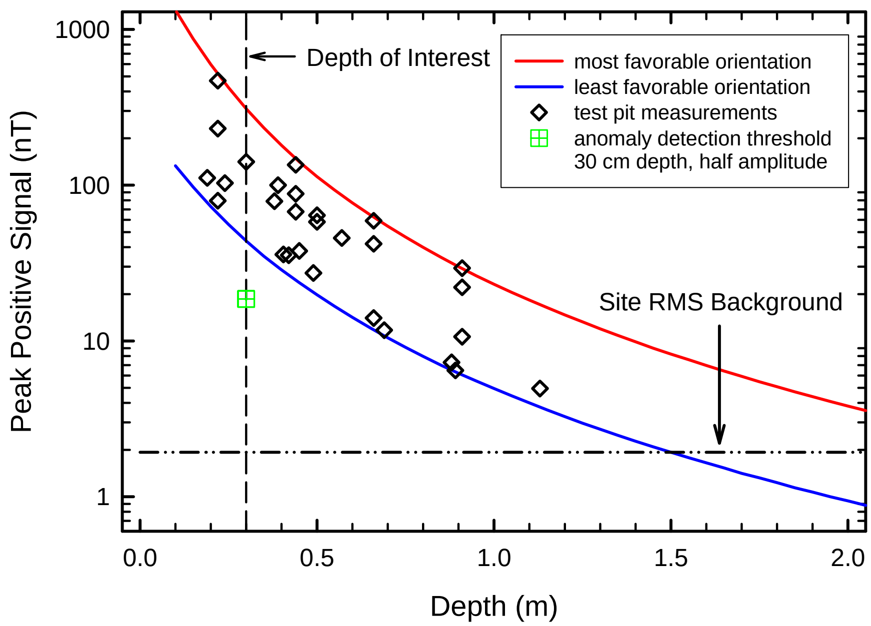


Figure 5-21 – MTADS Magnetometer array / 81mm Mortar response curve. The colored line represents the maximum (red) and minimum (blue) predicted responses for the system-item pairing as a function of depth. Test pit measurements are shown as open black diamonds. The minimum response at the depth of interest is shown as a green square and the site RMS background level is shown as a black line (dash – double dot).

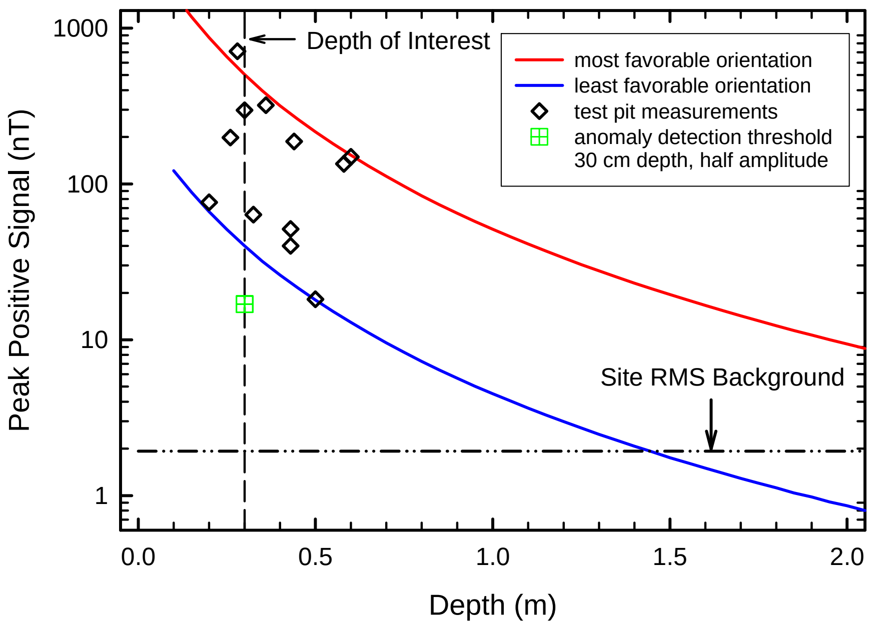


Figure 5-22 – MTADS magnetometer array / 2.36-in Rocket response curve. The colored line represents the maximum (red) and minimum (blue) predicted responses for the system-item pairing as a function of depth. Test pit measurements are shown as open black diamonds. The minimum response at the depth of interest is shown as a green square and the site RMS background level is shown as a black line (dash – double dot).

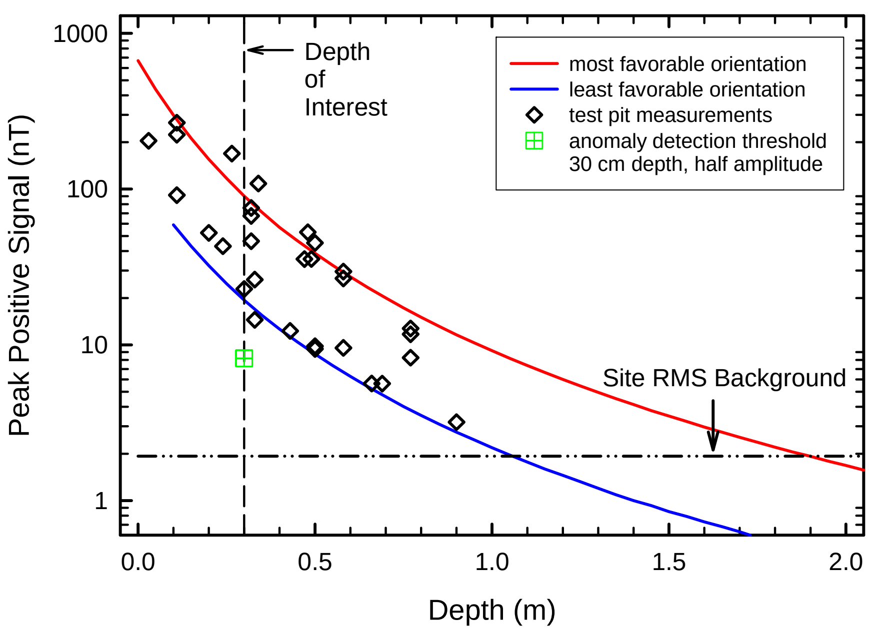


Figure 5-23 – MTADS Magnetometer array / 60mm Mortar response curve. The colored line represents the maximum (red) and minimum (blue) predicted responses for the system-item pairing as a function of depth. Test pit measurements are shown as open black diamonds. The minimum response at the depth of interest is shown as a green square and the site RMS background level is shown as a black line (dash – double dot).

Table 5-12 – MTADS Magnetometer Minimum Response Values by Munitions Type at a Depth of 30 cm with a 50% Amplitude Safety Factor

Description	Magnetometer (nT)
60mm	8.2
81mm	18.6
2.36-in rocket	16.9
4.2-in mortar	66.4

5.5.10 Magnetometer Survey Data

Based on the response curves and collective threshold of 8.2 nT, 5515 threshold exceedances were extracted from the magnetometer array data set for the demonstration site. Threshold exceedances located in the 'Vehicular Area" were excluded after discussion with the Program Office. A data segment around each threshold exceedance was extracted and analyzed using the UX-Analyze subsystem of Oasis montaj software package as described in Section 6.4 to fit the data to a dipole model and extract the associated fit parameters (position, depth, equivalent size) in an unattended batch mode. These results were then given to an experienced data analyst to review each anomaly individually. The data analyst reviewed and ranked each anomaly based on a strategy previously used successfully to rank magnetometer anomalies for further investigation by the MTADS TEMTADS array at the APG demonstration of the system in Summer 2008 [23]. The ranking details are listed below in Table 5-13. The cut-off values used were chosen by the expert data analyst based on experience and no effort was made to fine tune the results. The fit coherence cut-off value designating a decent fit was set at 0.85; the size cut-off value used was 0.030 m on the lower end (60 mm Mortar / 2.36-in Rocket) and 0.175 m on the upper end (4.2-in Mortar); and the solid angle cut-off value was set to 80^{o}. Using these criteria, Ranks 1, 2, & 3 (anomalies of possible interest) include 1463 anomalies. If items with remnant magnetization are included, the number raises to 1684 or 1857, depending on whether one includes just the 'good' fits or all fits, respectively, where the solid angle was greater than the cut-off value.

The magnetometer array data set is provided on the attached DVD. The anomaly fit parameter results are also provided on the attached DVD as an Excel spreadsheet.

Table 5-13 – Magnetometer Anomaly Ranking Scheme for Former Camp SLO Anomalies

Rank	Number Of Anomalies	Description
1	1087	Decent fit (coherence $\geq .85$) with the possibility as a candidate [size between a 60mm and a 4.2" mortar ($0.030 \text{ m} \leq \text{size} \leq 0.175 \text{ m}$)]
2	320	Poor fit (coherence < .85) but can not dismiss as a possible candidate (Reasons that may add to poor fits: partial anomaly, high density area / overlapping signatures, noisy area)
3	56	Would not fit, but cannot rule out possibility as a candidate (Reasons for no fits: partial anomaly, high density area / overlapping signatures, noisy area)
4	532	Decent fit with size too small as possible candidate (size < 0.030 m)
5	666	Anomaly caused by array bounce noise / geology
6	305	Anomaly caused by data processing artifacts
7a	221	Decent fit with high remnant magnetization (solid angle $\geq 80^{o}$)
7b	173	Poor fit with high remnant magnetization
8	1397	Poor fit – likely small clutter or noise
9	743	Would not fit – likely small clutter or noise
10	15	Decent fit with size too large as possible candidate (size > 0.175 m)

5.6 VALIDATION

At the conclusion of data collection activities, all anomalies on the master anomaly list assembled by the Program Office will be excavated in addition to the seed and the calibration strip items. Each item encountered will be identified, photographed, its depth measured, its location determined using cm-level GPS, and the item removed if possible. All non-hazardous items will be saved for later in-air measurements as appropriate. This ground truth information, once released, will be used to validate the objectives listed in Sections 3.0 and 7.0.

6.0 DATA ANALYSIS PLAN

6.1 SYSTEM-SPECIFIC DETECTION THRESHOLD DETERMINATION

For both the magnetometer and EM61 MkII array data sets, each threshold exceedance was identified and analyzed in a manner similar to that used for the Former Camp Sibert demonstrations [9]. For each exceedance, the data surrounding the peak center were extracted and submitted to the physics-based models resident in UX-Analyze. The modeling routines return the fit parameters (northing, easting, depth, size, etc.) for each peak. The process of selecting an appropriate detection threshold requires information about the items of interest, the response of the sensor used to each item of interest, and the goals of the demonstration especially in terms of the depth of interest. Based on archival information, the items of interest for this site were the 60mm, 81mm, and 4.2-in mortars and the 2.36-in rocket. The detection threshold for each sensor system was selected based on the smallest predicted peak magnitude for the items of interest at the depth of interest as discussed earlier in Sections 5.5.6 and 5.5.9. As each item of interest could be positioned in a range of orientations and at a range of depths, response curves were generated bounding the sensor response at the most favorable orientation and at the least favorable orientation of the sensor / item of interest pair with respect to the exciting field and as a function of depth.

An example is given in Figure 6-1 for the NRL EM61 MkII Array and a 4.2-in mortar. The upper curve represents the sensor response (in mV, S1) for the most favorable orientation of the projectile with respect to the exciting field (the EM61 transmitter coils) as a function of depth below the surface. The sensors travel an additional 33 cm above the surface. The lower curve represents the response for the least favorable orientation. Representative values of actual field measurements are shown as open, black diamonds. The background level at the GPO on the same site is also shown. The demonstration design set the initial depth of interest to be 11x the diameter of the item of interest, or 1.17m for the 4.2-in mortar. At this depth, the detection threshold was set to be one-half the least-favorable predicted response by the Program Office and the Advisory Group. The detection threshold was based on the demedianed S1 (bottom coil, 308 μs) data. In this example where the least favorable response is predicted to be 50 mV, S1, the anomaly detection threshold would be therefore 25 mV, S1.

This approach was used to establish the system response as a function of depth and to determine the appropriate detection thresholds for both arrays using field measurements made prior to deployment at our Blossom Point facility in our test pit. Using non-metallic spacers and shims, examples of each item of interest will be at a series of depths and orientations or ‘scenes.’ Four examples are shown in Figure 6-2 for the 4.2-in mortar. Data were collected using both arrays in turn over the series of ‘scenes.’

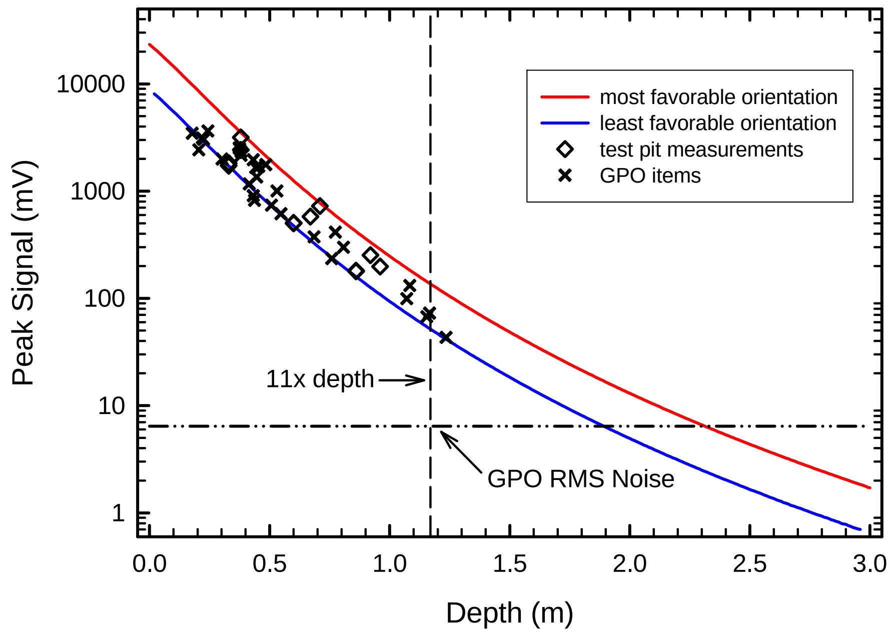
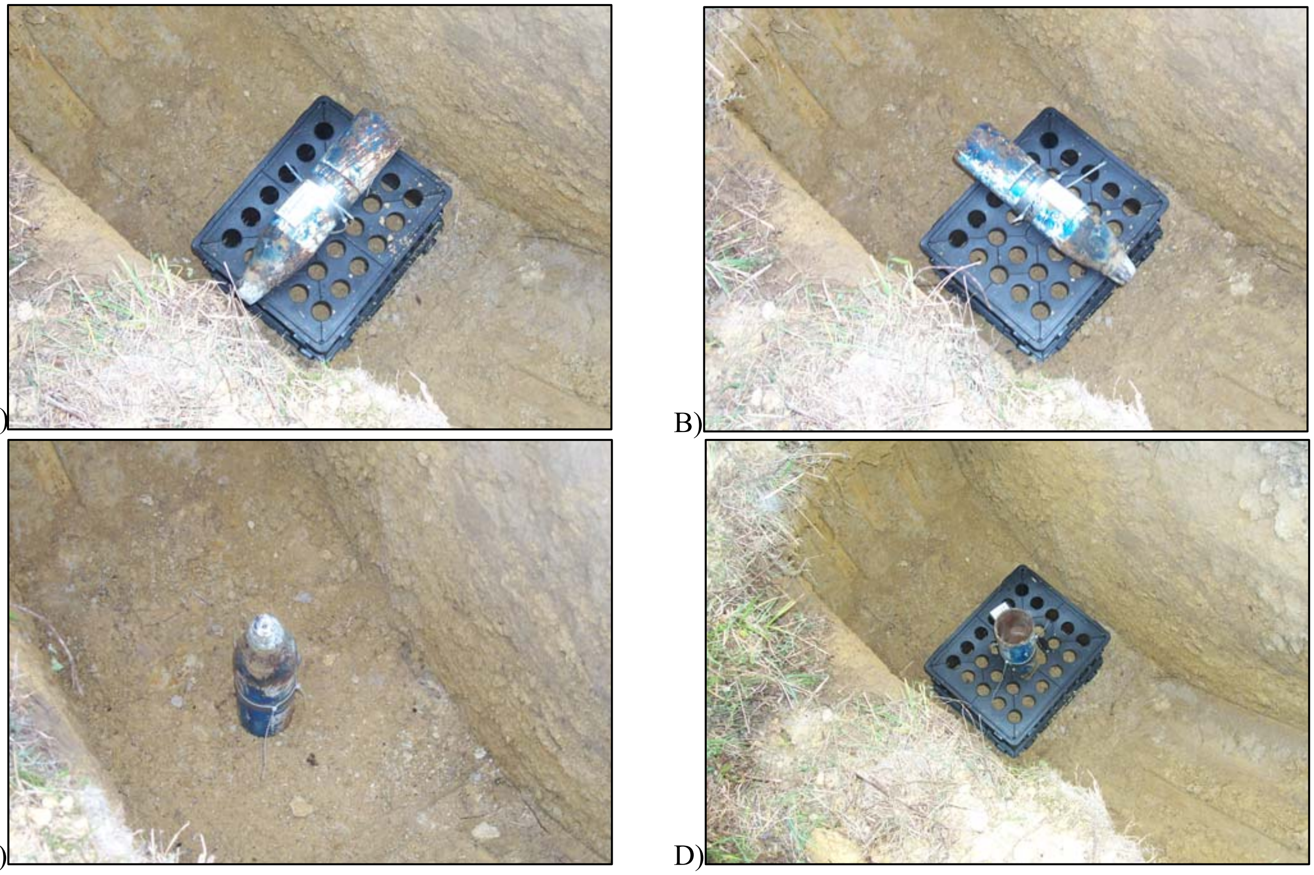


Figure 6-1 – Peak anomaly amplitude results from the MTADS EM61 MkII array system and pit measurements of the 4.2-in mortar (open diamonds). The modeled system response for the most (red) and least (blue) favorable orientations of the mortar are shown as lines. The responses for the seeded GPO items are also shown as 'x's.

For each sensor / item of interest pair, the peak positive value was extracted from the demedianed data for each 'scene.' The segment of data surrounding each item of interest for each 'scene' was also extracted and fit to the dipole model. An ensemble average of the results from all scenes was then used to generate a physics-based set of system response curves, like those shown in Figure 6-1. The test pit data and the generated curves are shown in Sections 5.5.6 and 5.5.9. The smallest detection threshold for each system was then selected as the overall detection threshold of the system. Two types of safety factors were considered for each system, a 50% safety factor in the depth of interest (45 cm based on the 30 cm determined from intrusive investigations), and a 50% amplitude safety factor like the one used for the Camp Sibert demonstration. For the EM61 MkII array, the 50% depth safety factor was the most conservative and for the Magnetometer array, the 50% amplitude safety factor was the most conservative. The RMS background levels for each sensor system were determined to verify the appropriateness of the sensor system for each item of interest and the site.



A) B) C) D)

Figure 6-2 – Example ‘scenes’ from pit measurements at Former Camp Sibert Site 18 of the 4.2-in mortar. A) Horizontal facing west, B) Horizontal facing north, C) Vertical nose up D) Vertical nose down.

6.2 SURVEY DATA PREPROCESSING

The collected raw magnetometer data were preprocessed on site for quality assurance purposes using standard MTADS procedures and checks as outlined in Section 5.5.3. The various data files were merged and imported into a single Oasis montaj (v6.4, Geosoft, Inc.) database using custom scripts developed from the original MTADS DAS routines which have been extensively validated. The collected raw EM61 MkII data were preprocessed using a similar set of routines incorporated into the MTADS DAS.

As part of the import process any data corresponding to a magnetometer outage, a GPS outage, or a vehicle stop / reverse, were defaulted or marked to not be further processed. Defaulted data were not deleted and could be recovered at a later time if so desired. Any long wavelength features such as the diurnal variation of the earth’s magnetic field and large scale geology were filtered from the data (demedianed).

The located, demedianed data were then collected into montaj database file. The located demedianed data were exported into a variety of GIS-compatible formats for further use, delivery, and for archival purposes.

6.3 DETECTION OF THRESHOLD EXCEEDANCES

Using the sensor-specific detection threshold determined using the process outlined in Section 6.1, all threshold exceedances for the corresponding data set were located using a built-in feature of Oasis montaj (gridpeak.gx) in a manner similar to that used during the Former Camp Sibert demonstration [9] and further details are available within the reference. A regularly-spaced mesh, or grid, is generated from each data set. Based on experience from Former Camp Sibert, a grid with a mesh size of 25 cm typically offers the best trade-off of detection sensitivity and false positive detections. While the facility for applying one or more passes of a smoothing filter prior to detection is available in the software, this feature was not used at the Former Camp Sibert for increased transparency in the data analysis process. The suitability of the peak detection parameters was verified prior to the final peak detection run for this demonstration. Analysis of the EM61 MkII data from this demonstration showed that the use of the smoothing feature caused a large fraction of small, yet compact threshold exceedances to fall below the detection threshold even after calibrating (reducing) the threshold to account for the effects of the smoothing. Since the nature of the objects generating the small, compact peaks are not currently known, a conservative approach was taken by not applying smoothing prior to threshold extraction.

6.4 PARAMETER ESTIMATION

The located, demedianed data from each sensor array were imported into the UX-Analyze subsystem of Oasis montaj. The data surrounding the center of each selected anomaly were extracted using tools developed by Geosoft and SAIC (AETC). The resulting data chips were submitted to the resident physics-based models to determine anomaly size, position, and depth, and in the case of the EM61 MkII data, a measure of shape in an unattended batch mode. The results for each anomaly were then reviewed by an expert data analyst. An Anomaly Fit Result list containing the details of the anomaly location and fit parameters and any comments from the data analyst was then generated for each data set and are provided on the attached DVD. The located, sensor data are also provided as deliverables.

6.5 DATA PRODUCT SPECIFICATIONS

See Appendix C for the detailed data product specifications.

7.0 PERFORMANCE ASSESSMENT

Performance objectives for the demonstration are given in Table 7-1 to provide a basis for evaluating the performance of the demonstrated technologies. These objectives are for the technologies being demonstrated only. Overall project objectives are given in the overall demonstration documentation generated by ESTCP. Preliminary performance results for this demonstration are given here, where the necessary data are currently available. This section will be revised in later versions as additional data become available.

7.1 OBJECTIVE: SITE COVERAGE

The collection of a complete, high-quality data set with each sensor platform is critical to the downstream success of the UXO Classification Study. This objective considers one of the data quality issues, site coverage of the data collection.

7.1.1 Metric

Site coverage is defined as the fraction of the designated survey area surveyed by each sensor platform. Exceptions are to be made for topology / vegetation interferences.

7.1.2 Data Requirements

The spatial extend of the collected data was compared to the original site boundaries as provided. Any interferences will be noted in the field log book.

7.1.3 Success Criteria

The objective was considered met if 100% of the demonstration site was surveyed with the exception of areas that could not be surveyed due to topology / vegetation interferences.

7.1.4 Results

This objective was successfully met. The presence of certain non-navigable features such as concrete targets / bunkers and large rocks limited the extent to which parts of the area could be surveyed. With the exception of these non-navigable features, 100% of the demonstration site was surveyed successfully with both sensor systems as shown in Figure 5-14 and Figure 5-19. Where non-navigable features prevented data collection, at least one additional pass was attempted in another survey direction to maximize the survey coverage.

Table 7-1 – Preliminary Performance Results for This Demonstration

Performance Objective	Metric	Data Required	Success Criteria	Success?
Quantitative Performance Objectives				
Site Coverage	Fraction of assigned coverage completed	Survey results	100% as allowed for by topography / vegetation	Yes
Data Density	Average number of data points per meter^2	Survey results	> 20 pts/m^2 for MkII > 60 pts/m^2 for Mag	Yes
Calibration Strip Results	System response consistently matches physics-based model	• System response curves • Daily calibration strip data	• ≤ 15% rms variation in amplitude • Down-track location ± 25cm • All response values fall within bounding curves	Yes
Detection of all Munitions of Interest	Percent detected of seeded items	• Location of seeded items • Anomaly list	At least 98% of seeded items detected	
Location Accuracy	Average error and standard deviation in both axes for interrogated items	• Estimated location from analyses • Ground truth from validation effort	ΔN and ΔE < 10 cm σN and σE < 15 cm	
Depth Accuracy	Standard deviation in depth for interrogated items	• Estimated location from analyses • Ground truth from validation effort	• ≥ 30cm: < 30% • < 30cm: ≤ 15 cm	
Production Rate	Number of acres surveyed each day	• Survey results • Log of field work	5 acres/day for MkII 20 acres/day for Mag	Yes
Data Throughput	Throughput of data QC process	Log of analysis work	All data QC'ed on site and at pace with survey	Yes
Qualitative Performance Objective				
Reliability and Robustness	General Observations	Team feedback and system logs	Field team comes to work smiling	Yes

7.2 OBJECTIVE: DATA DENSITY

The collection of a complete, high-quality data set with each sensor platform is critical to the downstream success of the UXO Classification Study. This objective considers one of the key data quality issues, the data density of the data collection.

7.2.1 Metric

Data density is defined as the number of data points collected during the data collection process per square meter. The performance was determined as the average value for the entire area surveyed.

7.2.2 Data Requirements

The collected data were used to determine the performance. The site boundaries as provided were also required.

7.2.3 Success Criteria

The objective was considered met if the average data density for the final data set is > 20 points / square meter for the EM61 MkII array and > 60 points / square meter for the magnetometer array.

7.2.4 Results

This objective was successfully met. As discussed in Section 5.5.2, the simple ratio of number of valid data points within the site boundary (including the Vehicular Area and the boundary of the path within the site) by the site area in m^2 results in data densities in excess of the success metrics. The specific values are provided in Table 5-9.

7.3 OBJECTIVE: CALIBRATION STRIP RESULTS

This objective supports that each sensor system was in good working order and collecting physically valid data each day of field work. The calibration strip was surveyed at least twice daily. The peak positive response of each emplaced item from each run was compared to both the ensemble average for reproducibility and to the physics-based response curves generated prior to data collection for each item of interest for physical reasonableness.

7.3.1 Metric

The reproducibility of the measured response of each sensor system to the items of interest and the comparison of the response to the response predicted by the physics-based model defines this metric.

7.3.2 Data Requirements

Response curves for each sensor / item of interest pair were used to document what the physics-based response of the system to the item should be. The tabulated peak response values determined from the twice-daily surveys of the calibration strip data demonstrates the reproducibility and validity of the sensor readings.

7.3.3 Success Criteria

The objective was considered met if the measured responses fall within the range of physically possible values based on the appropriate response curve, and if the RMS variation in responses was less than 15% of the measured response. Additionally, the down-track fit location of each anomaly was required to be within 25 cm of the corresponding seeded item's true location.

7.3.4 Results

This objective was successfully met. The repeatability of the system responses was addressed previously in Section 5.4.2. Table 5-7 summarizes the results for the magnetometer array where the RMS variation for all emplaced items was less than 7% of the aggregate average peak value. Table 5-8 summarizes the results for the EM61 MkII array where the RMS variation for all emplaced items was less than or equal to 10% of the aggregate average peak value with the exception of emplaced item T-005, the 60mm Mortar positioned horizontally and at 120 degrees azimuth, with an RMS variation of 26%. None of the recorded responses for this emplaced item were below the final threshold exceedance value. This is most likely due to the wider sensor spacing of the MkII array as compared to the magnetometer array and the lack of the orthogonal pass used on the main field. This issue was not observed at the former Camp Sibert demonstration and suggests that the orthogonal pass on the calibration strip may be a useful, if time-consuming, addition as suggested by some of the data processing demonstrators for this demonstration.

The measured peak amplitudes of each emplaced item were compared to the physics-based response curved generated for the munitions of interest in the test pit prior to the demonstration. The peak values for the 60mm Mortar are plotted in Figure 7-1 for the EM61 MkII array and Figure 7-2 for the magnetometer array as examples since the 60mm Mortar was the limiting case for both systems. As can be seen, the measured values are bounded by the predicted minimum response curve, indicating that all of these items would be detected using a threshold determined in the manner discussed in Section 6.1.

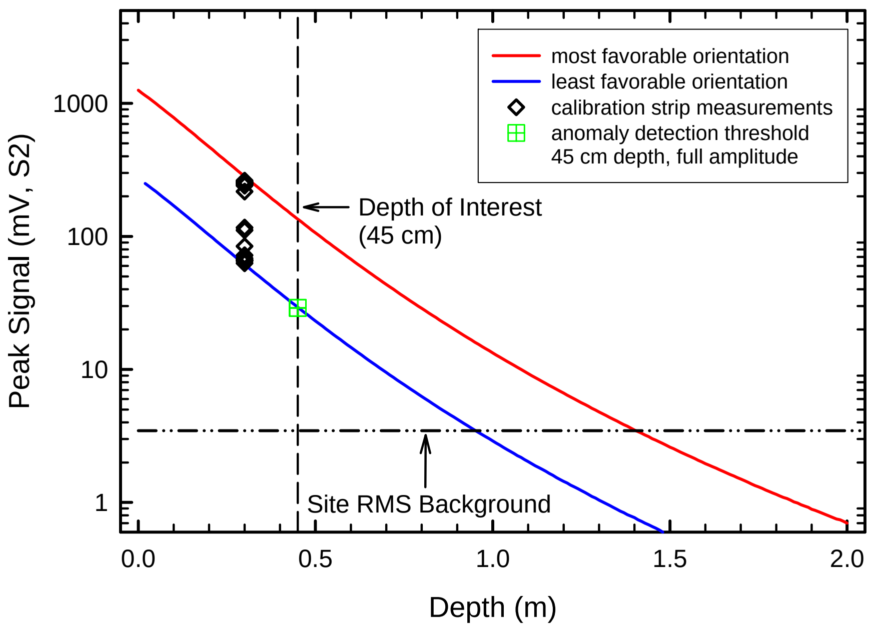


Figure 7-1 – MTADS EM61 MkII calibration strip responses (S2, open diamonds) for the 60mm Mortar. The curves represent the maximum (red) and minimum (blue) predicted responses for the system-item pairing as a function of depth. The minimum response at the depth of interest is shown as a green square.

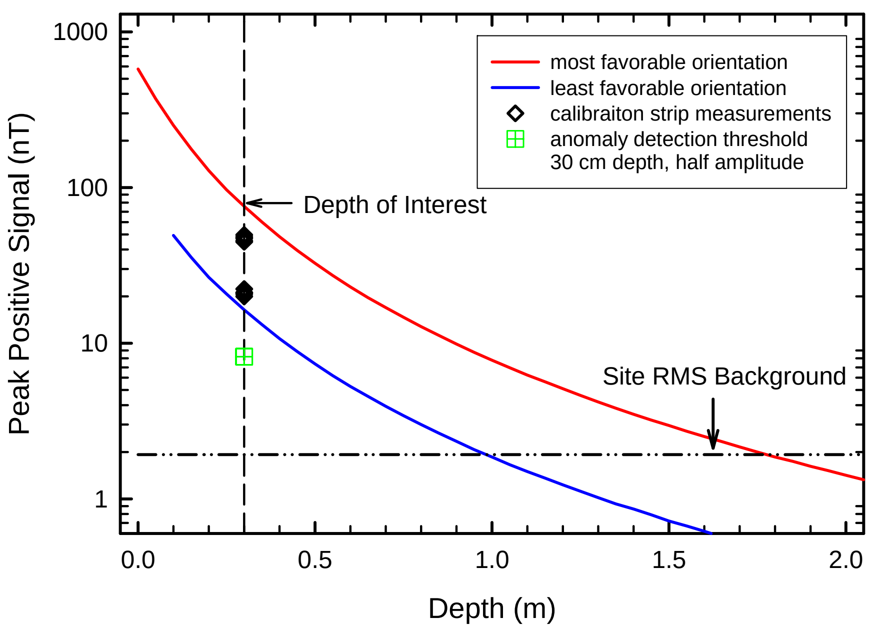


Figure 7-2 – MTADS Magnetometer calibration strip responses (open diamonds) for the 60mm Mortar. The curves represent the maximum (red) and minimum (blue) predicted responses for the system-item pairing as a function of depth. The minimum response at the depth of interest is shown as a green square.

The variability and accuracy of the anomaly position fit parameters were monitored by looking at the reported position and the down-track error for the calibration strip emplaced items, whose positions are nominally known. To provide a frame of reference for defining down- and cross-track, a line was fit to the reported northing and easting positions of the calibration strip emplaced items using the northing as the independent variable as the calibration strip was most closely aligned north to south. For each survey of the calibration strip, the distance from the fit position of each anomaly to the fit position on the line of the corresponding emplaced item was determined and decomposed into down- and cross-track components. The aggregate results are given in Table 7-2 and Table 7-3 for the magnetometer and EM61 MkII arrays, respectively. The average value represents the accuracy of the anomaly fit position with respect to the 'fit' reported location and the standard deviation represents the reproducibility of the fit position. The average offsets of several items are quite large, approaching the 25 cm level. It is possible that some or all of the emplaced items shifted / settled in the eight month period between emplacement and data collection. The items are scheduled for recovery and reacquisition during the digging phase of the Study, so this issue could be revisited at that time.

Table 7-2 – Magnetometer Array Position Accuracy and Variability for Calibration Strip Emplaced Items

Item ID	**Description**	**Depth (m)**	**Inclination**	**Offset (m)**	**Std. Dev (m)**	**Cross Track (m)**	**Std. Dev (m)**	**Down Track (m)**	**Std. Dev (m)**
T-001	shotput	0.25	N/A	0.18	0.02	0.02	0.01	0.18	0.02
T-002	81mm	0.30	Vertical Down	0.20	0.02	0.03	0.01	0.20	0.02
T-003	81mm	0.30	Horizontal	0.14	0.02	0.14	0.02	0.02	0.02
T-004	60mm	0.30	Vertical Down	0.03	0.02	0.02	0.02	0.02	0.02
T-005	60mm	0.30	Horizontal	0.19	0.02	0.17	0.01	0.08	0.01
T-006	4.2-in mortar	0.30	Vertical Down	0.19	0.05	0.11	0.03	0.16	0.04
T-007	4.2-in mortar	0.30	Horizontal	0.03	0.01	0.02	0.02	0.02	0.01
T-008	2.36-in rocket	0.30	Vertical Down	0.12	0.03	0.10	0.03	0.06	0.02
T-009	2.36-in rocket	0.30	Horizontal	0.05	0.01	0.04	0.01	0.02	0.02
T-010	shotput	0.35	N/A	0.54	0.07	0.25	0.02	0.48	0.07
			Average	**0.17**		**0.09**		**0.12**	

Table 7-3 – EM61 MkII Array Position Accuracy and Variability for Calibration Strip Emplaced Items

Item ID	Description	Depth (m)	Inclination	Offset (m)	Std. Dev (m)	Cross Track (m)	Std. Dev (m)	Down Track (m)	Std. Dev (m)
T-001	shotput	0.25	N/A	0.23	0.05	0.07	0.06	0.21	0.04
T-002	81mm	0.30	Vertical Down	0.26	0.03	0.10	0.05	0.23	0.05
T-003	81mm	0.30	Horizontal	0.14	0.06	0.130	0.06	0.03	0.02
T-004	60mm	0.30	Vertical Down	0.20	0.19	0.190	0.20	0.05	0.03
T-005	60mm	0.30	Horizontal	0.30	0.09	0.27	0.07	0.13	0.05
T-006	4.2-in mortar	0.30	Vertical Down	0.21	0.18	0.10	0.21	0.14	0.06
T-007	4.2-in mortar	0.30	Horizontal	0.18	0.09	0.07	0.05	0.15	0.10
T-008	2.36-in rocket	0.30	Vertical Down	0.21	0.05	0.08	0.04	0.19	0.06
T-009	2.36-in rocket	0.30	Horizontal	0.21	0.16	0.21	0.16	0.03	0.03
T-010	shotput	0.35	N/A	0.30	0.13	0.27	0.14	0.11	0.04
			Average	**0.22**		**0.15**		**0.13**	

7.4 OBJECTIVE: DETECTION OF ALL MUNITIONS OF INTEREST

Quality data should lead to a high probability of detecting the munitions of interest at the site.

7.4.1 Metric

The metric for this objective is the percentage of seed items that were detected using the specified anomaly selection threshold.

7.4.2 Data Requirements

An anomaly list was prepared for both the EM61 MkII and magnetometer array systems and submitted for scoring. IDA personnel will score the detection probability of the seeded items.

7.4.3 Success Criteria

This objective was considered to be met if at least 98% of the seeded items were detected.

7.4.4 Results

Official results from IDA are not currently available to address the success of this metric. The success of this metric will be evaluated in later versions of this document when the required data are available.

7.5 OBJECTIVE: LOCATION ACCURACY

An important measure of how efficiently any required remediation will proceed is the accuracy of predicted location of the targets marked to be dug. Large location errors lead to confusion

among the UXO technicians assigned to the remediation costing time and often leading to removal of a small, shallow object when a larger, deeper object was the intended target.

7.5.1 Metric

The average error and standard deviation in both horizontal axes were computed for the items which are selected for excavation during the validation phase of the study. This metric only applied to the fit result locations, not the threshold exceedance locations.

7.5.2 Data Requirements

The anomaly fit results and the ground truth for the excavated items were required to determine the performance of the fitting routines in terms of the location accuracy.

7.5.3 Success Criteria

This objective was considered as met if the average error in position for both Easting and Northing quantities was less than 10 cm and the standard deviation for both is less than 15 cm.

7.5.4 Results

The validation data results required to evaluate the success of this metric are not currently available. The success of this metric will be evaluated in later versions of this document when the required data are available.

7.6 OBJECTIVE: DEPTH ACCURACY

An important measure of how efficiently any required remediation will proceed is the accuracy of predicted depth of the targets marked to be dug. Large depth errors lead to confusion among the UXO technicians assigned to the remediation costing time and often leading to removal of a small, shallow object when a larger, deeper object was the intended target.

7.6.1 Metric

The standard deviation of the predicted depths with respect to the ground truth will be computed for the items which are selected for excavation during the validation phase of the study. This metric only applies to the fit result locations, not the threshold exceedance locations.

7.6.2 Data Requirements

The anomaly fit results and the ground truth for the excavated items will be required to determine the performance of the fitting routines in terms of the predicted depth accuracy.

7.6.3 Success Criteria

This objective was considered to be successful in two categories. For predicted depths of greater than 30 cm, the success criteria was an overall standard deviation of < 30%. For shallow items with depth less than 30 cm, the success criteria was an overall standard deviation of ≤ 15 cm.

7.6.4 Results

The validation data results required to evaluate the success of this metric are not currently available. The success of this metric will be evaluated in later versions of this document when the required data are available.

7.7 OBJECTIVE: PRODUCTION RATE

This objective considers a major cost driver for the collection of high-density, high-quality geophysical data, the production rate. The faster quality data can be collected, the higher the financial return on the data collection effort.

7.7.1 Metric

The number of acres or hectares per day surveyed by each sensor system determined the production rate for each survey system.

7.7.2 Data Requirements

The metric was determined from the combination of the field logs and the survey results. The field logs record the amount of time per day spent acquiring the data and the survey results determine the area surveyed in that time period.

7.7.3 Success Criteria

Typically, this objective would be considered met if the average production rate is at least 5 acres / day for the EM61 MkII array and at least 20 acres / day for the magnetometer array. Given the small size of the demonstration site, 11.8 acres, if the demonstration was completed as per the schedule, this objective was considered met.

7.7.4 Results

This objective was successfully met. The demonstration was completed as per schedule. The three-day shutdown for the repair of the tow vehicle transmission was made up through working longer days and through the weekend. This scale of ‘catch-up’ effort is only sustainable for such a small survey area.

7.8 OBJECTIVE: DATA THROUGHPUT

The collection of a complete, high-quality data set with each sensor platform is critical to the downstream success of the UXO Classification Study. This objective considers one of the key data quality issues, the ability of the data analysis workflow to support the data collection effort in a timely fashion. To maximize the efficient collection of high quality data, a series of MTADS standard data quality check are conducted during and immediately after data collection on site. Data which pass the QC screen are then processed into archival data stores. Anomaly selection and individual anomaly analyses are then conducted on those archival data stores. The data QC / preprocessing portion of the workflow needs to keep pace with the data collection effort for best performance.

7.8.1 Metric

The throughput of the data quality control workflow must be at least as fast the data collection process to provide real time feedback to the data collection team of any emergent issues.

7.8.2 Data Requirements

The data analysts log books provided the necessary data to determine the success of this metric.

7.8.3 Success Criteria

This objective was considered met if all collected data were processed through the data quality control portion of the workflow such that the data collection crew did not collect large amounts of data under non-ideal conditions for lack of feedback from the data analyst nor had to wait for feedback on data quality prior to moving on to a new task.

7.8.4 Results

This objective was successfully met. No significant backlogs in feedback were experienced.

7.9 OBJECTIVE: RELIABILITY AND ROBUSTNESS

This objective represents an opportunity for all parties involved in the data collection process, especially the vehicle operator, to provide feedback on areas where the process could be improved.

7.9.1 Data Requirements

Discussions with the entire field team and other observations will be used.

7.9.2 Results

This objective was successfully met. Initial limitations in the ability of the tow vehicle to traverse the site with the EM61 MkII array trailer identified the first day of field work were

corrected with the installation of a new transmission with a lower gear ratio and more robust gearing. No other significant issues were identified during the demonstration.

8.0 SCHEDULE OF ACTIVITIES

Figure 8-1 gives the overall schedule for the demonstration including deliverables. The delivery date for the magnetometer array anomaly list was extended from the original plan due to the large number of threshold exceedances extracted and the plan executed to properly analyze and rank these threshold exceedances.

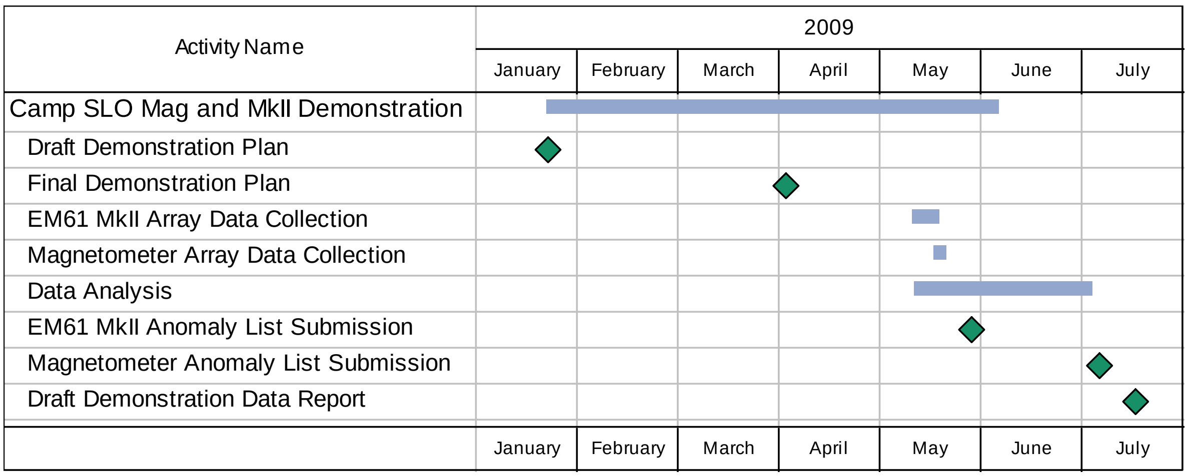


Figure 8-1 – Schedule of all demonstration activities including deliverables.

9.0 MANAGEMENT AND STAFFING

The responsibilities for this demonstration are outlined in Figure 9-1. Dan Steinhurst was the PI of this demonstration. Dan Steinhurst filled the roles of Site / Project Supervisor and served as Quality Assurance Officer. Glenn Harbaugh was the Site Safety Officer and Data Acquisition Operator. His duties included data collection and safety oversight for the entire team. Nagi Khadr served as the Data Analyst. Matt Whitman, Rick Cliffe, and Gustavo Alarcon of San Luis Personnel each served as Field Technicians for portions of the demonstration.

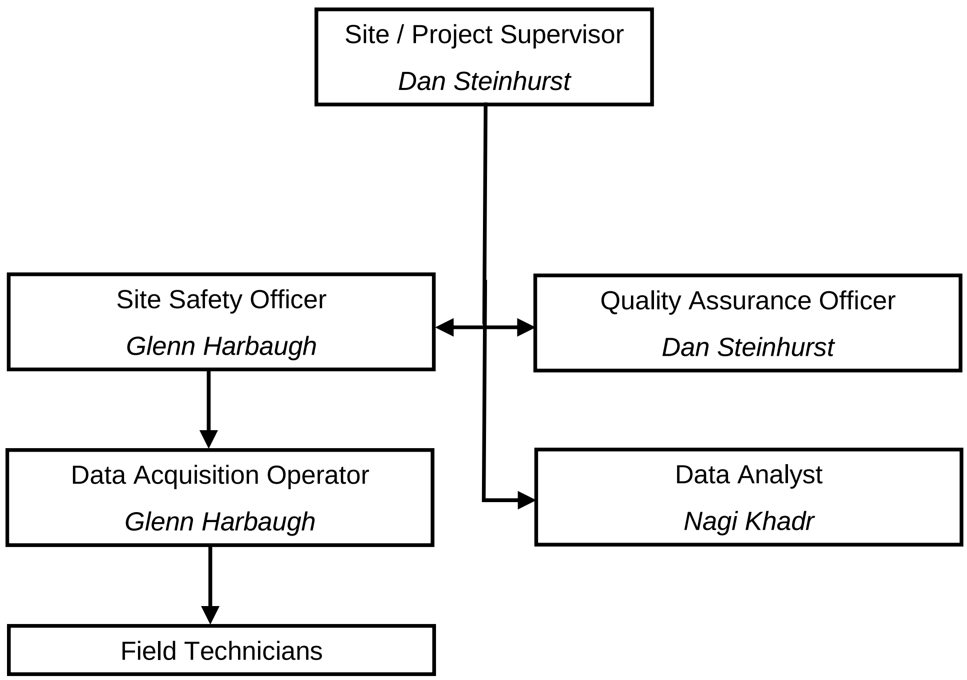


Figure 9-1 – Management and Staffing Wiring Diagram.

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16. “Airborne MTADS Demonstration at the Badlands Bombing Range, September, 2001,” J.R. McDonald, D.J. Wright, N. Khadr, H.H. Nelson, NRL/PU/6110—02-453.

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18. “MTADS Airborne and Vehicular Survey of Target S1 at Isleta Pueblo, Albuquerque, NM, 17 February – 2 March 2003,” H.H. Nelson, D. Wright, T. Furuya, J.R. McDonald, N. Khadr, D.A. Steinhurst, NRL/MR/6110—04-8764.

19. “Final Site Inspection Report, Former Camp San Luis Obispo, San Luis Obispo, CA,” Parsons, Inc., September 2007.

20. “Survey Control, Former Camp San Luis, Obispo,” August 18, 2008.

21. Geonics, Ltd., private communication, February, 2005.

22. “Moving Platform Orientation for an Unexploded Ordnance Discrimination System,” D. Steinhurst, N. Khadr, B. Barrow, and H. Nelson, GPS World, 2005, 16/5, 28 – 34.

23. “EMI Array for Cued UXO Discrimination, ESTCP MM-0601, Demonstration Data Report, APG Standardized UXO Test Site,” G.R. Harbaugh, J.B. Kingdon, T. Furuya, T.H. Bell, and D.A. Steinhurst, NRL/MR/6110—10-9234.

APPENDIX A. HEALTH AND SAFETY PLAN (HASP)

The ESTCP Program Office has prepared a Health and Safety Plan for the entire demonstration to provide a unified HASP for all demonstrators. All emergency information such as contact numbers and directions to nearby medical facilities are provided in that document.

APPENDIX B. POINTS OF CONTACT

POINT OF CONTACT	ORGANIZATION	Phone Fax e-mail	Role in Project
Dr. Jeff Marqusee	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-2120 (V) 703-696-2114 (F) jeffrey.marqusee@osd.mil	Director, ESTCP
Dr. Anne Andrews	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-3826 (V) 703-696-2114 (F) anne.andrews@osd.mil	Deputy Director, ESTCP
Dr. Herb Nelson	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-8726 (V) 703-696-2114 (F) 202-215-4844 (C) herbert.nelson@osd.mil	Program Manger, MM
Ms. Katherine Kaye	HydroGeoLogic, Inc. 11107 Sunset Hills Road, Suite 400 Reston, VA 20190	410-884-4447 (V) kkaye@hgl.com	Program Manager Assistant, MM
Dr. Dan Steinhurst	Nova Research, Inc. 1900 Elkin St., Ste. 230 Alexandria, VA 22308	202-767-3556 (V) 202-404-8119 (F) 703-850-5217 (C) dan.steinhurst@nrl.navy.mil	PI and Quality Assurance Officer
Mr. Glenn Harbaugh	Nova Research, Inc. 1900 Elkin St., Ste. 230 Alexandria, VA 22308	301-392-1702 (V) 804-761-5904 (C) glenn.harbaugh.ctr @nrl.navy.mil	Site Safety Officer
Dr. Nagi Khadr	SAIC 1225 S. Clark Street Suite 800 Arlington, VA 22202	217-531-9026 (V) nagi.khadr@saic.com	Data Analyst
Mr. David Ragsdale	California Polytechnic State University San Luis Obispo, CA 93407	805-756-6662 (V) 805-756-1602 (F) dragsdal@calpoly.edu	Environmental Health & Safety Manager / Risk Management

APPENDIX C. DATA FORMATS

C.1 MAGNETOMETER ARRAY

Each survey file set contains 11 files which constitute the 'raw data'. The file name structure is YYDDDFFF.DeviceType.DeviceAlias; where YY is the 2-digit year, DDD is the "Julian" day, or day in the year, and FFF is the flight number starting with 001. In the following example, the data were taken on the 210th day of 2002, flight number 4.

```
02210004.Survey.822A.822A_1
02210004.Survey.822A.822A_2
02210004.Survey.GPS.GPS_NMEA
02210004.Survey.AVR.AVR
02210004.Survey.SerialDevice.UTC
02210004.Survey.PpsDevice.PPS
02210004.Survey.TriggerDevice.Trigger
02210004.Survey.LineNumber
02210004.Survey
02210004.Survey.page
02210004.Survey.loginfo1.txt
```

Each data line is time stamped with the PC system clock to allow synchronization between files

YYDDDFFF.Survey.LineNumber
    Start and stop time of each line in survey, typically only one line / file
YYDDDFFF.Survey.822A.822A_1
    Output from Counter 1 (4 magnetometers), in nT x 10^5, 50 Hz.
YYDDDFFF.Survey.822A.822A_2
    Output from Counter 2 (4 magnetometers), in nT x 10^5, 50 Hz.
YYDDDFFF.Survey.PpsDevice.PPS
    Pulse per second (PPS) from GPS receiver, 1 Hz.
YYDDDFFF.Survey.GPS.GPS_NMEA
    GPS output, Trimble PTNL,GGK and PTNL,AVR sentences at 5 Hz (position).
YYDDDFFF.Survey.AVR.AVR
    GPS output, Trimble PTNL,GGK and PTNL,AVR sentences at 5 Hz (position).
YYDDDFFF.Survey.TriggerDevice.Trigger
    Trigger pulse to magnetometers, 50 Hz.
YYDDDFFF.Survey.SerialDevice.UTC
    UTC time tag from GPS receiver, "The time will be" message for next PPS, 1 Hz.

The .Survey, .Survey.page, and .Survey.loginfo*.txt files are setup information recorded by the data collection program and contain no data of use to the user.

.Survey.LineNumber files:

```
START LINE 0  12/21/04 12:45:39.523
STOP  LINE 0   12/21/04 12:59:21.072
```

Magnetometer (.822A) files:

```
d15289543808d25289567673d35289555967d45289802122  10/10/02 14:17:00.508
d15289545560d25289568728d35289557064d45289803821  10/10/02 14:17:00.528
d15289547878d25289569235d35289557743d45289805162  10/10/02 14:17:00.548
d15289547468d25289568538d35289557255d45289804417  10/10/02 14:17:00.568
d15289546204d25289567936d35289556456d45289802950  10/10/02 14:17:00.588
d15289545018d25289566714d35289556217d45289801466  10/10/02 14:17:00.608
```

First line:
d1 - Sensor 1 ok - two characters of status code / marker - other two character codes are possible to indicate error conditions
`5289543808 - 52895.43808 gamma or nT`
d2 - Sensor 2 ok
`5289567673 - 52895.67673 nT`
d3 - Sensor 2 ok
`5289555967 - 52895.55967 nT`
d4 - Sensor 2 ok
`5289802122 - 52898.02122 nT`

`10/10/02` - computer date stamp for receipt of string at computer.
`14:17:00.508` - computer time stamp for receipt of string at computer.

.Survey.PpsDevice.PPS files:

```
PPS   12/21/04 12:45:40.433
PPS   12/21/04 12:45:41.433
PPS   12/21/04 12:45:42.433
```

.Survey.GPS.GPS_NMEA and .Survey.AVR.AVR files:

```
$PTNL,GGK,144846.50,102208,3825.06252459,N,07706.25983318,W,3,09,2.7,EHT-
25.462,M*72  10/22/08 15:29:32.034
$PTNL,AVR,144846.40,+263.7942,Yaw,+0.4985,Tilt,,,1.872,3,2.7,9*04  10/22/08
15:29:32.055
$PTNL,GGK,144846.60,102208,3825.06252481,N,07706.25983303,W,3,09,2.7,EHT-
25.460,M*7C  10/22/08 15:29:32.137
$PTNL,AVR,144846.50,+263.7948,Yaw,+0.7564,Tilt,,,1.873,3,2.7,9*0E  10/22/08
15:29:32.158
```

Table C-1 – PTNL,GGK Message Fields

Field	Meaning[a]
1	UTC of position fix
2	Date
3	Latitude
4	Direction of Latitude (N = North, S = South)
5	Longitude
6	Direction of Longitude (E = East, W = West)
7	GPS Fix Quality (0 = Invalid,1,2,3,4)
8	Number of Satellites in fix
9	DOP of fix
10	Ellipsoidal height of fix
11	M: ellipsoidal height is measured in meters

[a] For further information, refer to the Trimble MS Series Operation Manual

The PTNL,AVR message format used in all files is given in Table C-2.

Table C-2 – PTNL,AVR Message Fields

Field	Meaning[a]
1	UTC of position fix
2	Yaw (degrees)
3	Yaw label
4	Tilt (degrees)
5	Tilt label
6	Reserved
7	Reserved
8	Range (meters)
9	GPS Fix Quality (0 = Invalid,1,2,3,4)
10	DOP of fix
11	Number of Satellites in fix

[a] For further information, refer to the Trimble MS Series Operation Manual

.Survey.SerialDevice.UTC files:

```
UTC 04.12.21 17:50:18 57  12/21/04 12:45:39.645
UTC 04.12.21 17:50:19 57  12/21/04 12:45:40.646
```

Located data archives are ASCII files of the format:

For located, demedianed magnetometer data:

```
GPS_Time    (seconds) UTC time of measurement in seconds since midnight
X           (UTM Zone X, NAD83, m) Easting
Y           (UTM Zone X, NAD83, m) Northing
Z           Height Above Ellipsoid (HAE, NAD83, m)
Heading     (degrees) Heading of the sensor platform as determined from GPS
                array
Pitch       (degrees) Pitch of the sensor platform as determined from GPS
                array
Roll        (degrees) Roll of the sensor platform as determined from GPS
                array
Mag_Fin     Signal in nT
```

where X is the appropriate UTM zone (10N for San Luis Obispo, CA)

Static Survey Archive (_static.xyz) files:
Daily static calibration run data will be archived as ASCII (.XYZ) files of the format:

```
GPS_Time        (seconds) UTC time of measurement in seconds since midnight
X_raw           (UTM Zone X, NAD83, m) Easting of GPS Antenna 1
Y_raw           (UTM Zone X, NAD83, m) Northing of GPS Antenna 1
Z_Raw           Height Above Ellipsoid (HAE, NAD83, m) of GPS Antenna 1
AVR_Yaw         (degrees) Heading of GPS array (not sensor platform)
AVR_Roll        (degrees) Roll of GPS array (not sensor platform)
AVR_Separation  (degrees) Separation of GPS array antennae
Mag1_Raw        (nT) Magnetometer data for sensor 1
Mag2_Raw        (nT) Magnetometer data for sensor 2
Mag3_Raw        (nT) Magnetometer data for sensor 3
Mag4_Raw        (nT) Magnetometer data for sensor 4
Mag5_Raw        (nT) Magnetometer data for sensor 5
Mag6_Raw        (nT) Magnetometer data for sensor 6
Mag7_Raw        (nT) Magnetometer data for sensor 7
Mag8_Raw        (nT) Magnetometer data for sensor 8
```

where X is the appropriate UTM zone (10N for San Luis Obispo, CA). Note that since the array is not moving, the data are not positioned.

MTADS Anomaly (Threshold Exceedence) Report Example

The example is given in ASCII text file format. Actual delivery will be in Excel Spreadsheet format.

```
Anomaly_ID,Anomaly X,Anomaly Y,Grid_value
0,578835.50,3751636.50,80.00,
1,578923.00,3751640.00,287.70,
```

```
2,578832.00,3751640.50,4341.80,
3,578840.00,3751640.50,30.00,
4,578855.50,3751642.50,206.10,
5,578871.50,3751642.50,26.50,
```

UX-Analyze Anomaly Report Example

The Geosoft Oasis montaj add-in, UX-Analyze was used to analyze anomalies for the Magnetometer data. The results are distributed as an Excel 2003 spreadsheet, but an excerpt is given in .csv format below for reference purposes.

```
ID,X,Y,Fit_X,Fit_Y,Fit_Size,Fit_Depth,Fit_Coh,Fit_MagneticMoment,Fit_SolidAng
le,Fit_inc,Fit_dec,Fit_Error,Grid_Value,Rank,Description
1,705272.5,3913630,705272.52,3913630.14,0.02,-
0.03,0.424,0,30.8,34.3,346.4,0,11.7,8,Poor fit – likely small clutter or
noise
2,705268.25,3913630.25,705268.41,3913630.4,0.025,-
0.05,0.933,0,49.8,33.3,79.5,0,32.6,4,Decent fit with size too small as
possible candidate (size < 0.030 m)
3,705285,3913630.25,705285.12,3913630.47,0.033,-
0.02,0.947,0,52.6,8.6,31.1,0,36.8,1,"Decent fit (coherence ? .85) with size
between a 60mm and a 4.2"" mortar ( 0.030 m ? size ? 0.175 m)]"
4,705299,3913630.25,705298.97,3913629.91,0.045,0.23,0.514,0,106.3,12.7,211.4,
0,33.3,5,Anomaly caused by array bounce noise / geology
5,705242.5,3913630.5,705242.73,3913630.64,0.019,-
0.06,0.864,0,56.6,13.6,58.6,0,12,4,Decent fit with size too small as possible
candidate (size < 0.030 m)
6,705292.25,3913630.75,705292.19,3913630.87,0.021,0.04,0.737,0,45.3,53.9,285,
0,11.3,8,Poor fit – likely small clutter or noise
7,705272.25,3913631,705272.37,3913630.81,0.021,-0.03,0.876,0,124.9,-
6.1,175.3,0,11.9,4,Decent fit with size too small as possible candidate (size
< 0.030 m)
8,705244,3913631.25,705244,3913631.53,0.02,-
0.06,0.865,0,48.6,11.8,1.1,0,16.3,4,Decent fit with size too small as
possible candidate (size < 0.030 m)
9,705281.25,3913631.25,705281.15,3913631.58,0.035,0.14,0.497,0,53.3,6.3,10.4,
0,17.5,8,Poor fit – likely small clutter or noise
```

C.2 EM61 MKII ARRAY

Each survey file set contains 13 files which constitute the ‘raw data’. The root filename structure is the same as for the magnetometer system. Each data line is time stamped with the PC system clock to allow synchronization between files

YYDDDFFF.Survey.GPS.GGK_AVR1

GPS output, Trimble PTNL,GGK sentence at 10-20 Hz (position), PTNL,AVR sentence for MB1 / MB2 receiver pair at 10 Hz (orientation).

YYDDDFFF.Survey.AVR.AVR1

GPS output, Trimble PTNL,GGK sentence at 10-20 Hz (position), PTNL,AVR sentence for MB1 / MB2 receiver pair at 10 Hz (orientation). Duplicate of GGK_AVR1 information.

YYDDDFFF.Survey.AVR.AVR2

GPS output, Trimble PTNL,AVR sentence for MB2 / MR receiver pair at 10 Hz (orientation).

YYDDDFFF.Survey.EM61MII.EM61_MkII_1

Output from Sensor #1 (Port), 4 time gates (counts), Transmit current (counts), and battery voltage (counts).

YYDDDFFF.Survey.EM61MII.EM61_MkII_2

Output from Sensor #2 (Center), 4 time gates (counts), Transmit current (counts), and battery voltage (counts).

YYDDDFFF.Survey.EM61MII.EM61_MkII_3

Output from Sensor #3 (Starboard), 4 time gates (counts), Transmit current (counts), and battery voltage (counts).

YYDDDFFF.Survey.LineNumber

Start and stop time of each line in survey, typically only one line / file

YYDDDFFF.Survey.PpsDevice.PPS

Pulse per second (PPS) from GPS receiver, 1 Hz.

YYDDDFFF.Survey.SerialBinDevice.IMU

Output from IMU (pitch, roll, angular rates, accelerations, etc.) in packed binary format. Data Rate is typically 30 Hz.

YYDDDFFF.Survey.SerialDevice.UTC

UTC time tag from GPS receiver MR, "The time will be" message for next PPS, 1 Hz.

The .Survey, .Survey.page, and .Survey.loginfo*.txt files are setup information recorded by the data collection program and contain no data of use to the user. The EM61 MkII and IMU data file formats are packed binary data formats with an ASCII date/time tag appended to each data packet. The data packet formats are described each manufacturer's manuals and technical notes and are not reproduced here.

.Survey.GPS.GGK_AVR1 files:

```
$PTNL,GGK,154409.65,010907,3251.14866418,N,11416.21512783,W,3,06,3.7,EHT120.6
47,M*67  01/09/07 15:33:36.583
$PTNL,GGK,154409.70,010907,3251.14866416,N,11416.21512781,W,3,06,3.7,EHT120.6
47,M*6F  01/09/07 15:33:36.633
$PTNL,AVR,154409.60,+285.3082,Yaw,+2.4128,Tilt,,,1.917,3,3.7,6*08  01/09/07
15:33:36.654
```

The AVR1 data file contains a redundant copy of the MB1 / MB2 PNTL,AVR message. The AVR2 files contains the MB2/MR PNTL, AVR message. The PTNL,AVR message format used in all files is given in Table C-2.

Located data archive files are in an ASCII format of the form:

For located, demedianed EM61 MkII data:

```
t                 (seconds) UTC time in seconds past midnight
x                 (UTM Zone X, NAD83, m) Easting for sensor
y                 (UTM Zone X, NAD83, m) Northing for sensor
z                 (NAD83, m) Height above Ellipsoid for sensor
```

cog	(degrees) Heading of array in DAS frame, East = 0 degrees
gps_yaw	(degrees) Yaw of the sensor platform as determined from GPS array
gps_pitch	(degrees) Pitch of the sensor platform as determined from GPS array
gps_roll	(degrees) Roll of the sensor platform as determined from GPS array
combined_pitch	(degrees) Pitch of the sensor platform as determined from GPS and IMU
combined_roll	(degrees) Roll of the sensor platform as determined from GPS and IMU
imu_pitch	(degrees) Pitch of the sensor platform as determined from IMU
imu_roll	(degrees) Roll of the sensor platform as determined from IMU
ID	Denotes which sensor the data were recorded from
s1_Fin	(mV) Demedianed magnetometer data for first gate, bottom coil
s2_Fin	(mV) Demedianed magnetometer data for second gate, bottom coil
s3_Fin	(mV) Demedianed magnetometer data for third gate, bottom coil
s4_Fin	(mV) Demedianed magnetometer data for fourth gate, bottom coil
current	Transmitter current reading from EM61 MkII console (Counts). 3,000 counts is Geonics baseline value
voltage	Battery voltage reading from EM61 MkII console (Volts)
fid	Fiducial value for data point
filename	Filename of source data file

where X is the appropriate UTM zone (10N for San Luis Obispo, CA)

Static Survey Archive (_static.xyz) files:
Daily static calibration run data are archived as Geosoft .XYZ files in the same format as the data archives.

MTADS Anomaly (Threshold Exceedence) Report Example

The example is given in ASCII text file format. Actual delivery will be in Excel Spreadsheet format.

```
Anomaly_ID,Anomaly X,Anomaly Y,Grid_value
0,578835.50,3751636.50,80.00,
1,578923.00,3751640.00,287.70,
2,578832.00,3751640.50,4341.80,
3,578840.00,3751640.50,30.00,
4,578855.50,3751642.50,206.10,
5,578871.50,3751642.50,26.50,
```

UX-Analyze Anomaly Report Example

The Geosoft Oasis montaj add-in, UX-Analyze was used to analyze anomalies for the EM61 MkII data. The results are distributed as an Excel 2003 spreadsheet, but an excerpt is given in .csv format below for reference purposes.

```
ID,X (m),Y (m),"Grid_value (mV, S2)",Fit_X (m),Fit_Y (m),Fit_Depth
(m),Fit_Size
(m),Fit_chi2,Fit_Coh,Comments,Comments_2,Fit_b1,Fit_b2,Fit_b3,Fit_phi
(deg),Fit_psi (deg),Fit_theta (deg)
0,705272.50,3913630.50,38.51,705272.308,3913630.761,0.278,0.020,28.39,0.8622,
Anomalies 000/001,,0.0400,0.0151,0.0092,146.43,-74.15,-13.84
1,705272.25,3913631.25,37.36,705272.307,3913630.761,0.267,0.020,26.68,0.8694,
Anomalies 000/001,,0.0380,0.0143,0.0090,146.15,-73.70,-13.66
2,705281.50,3913631.25,40.54,705281.349,3913631.634,0.595,0.034,33.67,0.8152,
Poor Fit.  Anomalies 002/003,,0.2540,0.0568,0.0000,336.22,-81.34,8.71
3,705281.00,3913632.00,35.41,705281.255,3913631.632,0.643,0.036,46.51,0.7569,
Poor Fit.  Anomalies 002/003,,0.3190,0.0667,0.0000,333.27,97.34,9.19
4,705289.00,3913632.00,74.30,705289.315,3913632.194,0.672,0.042,34.47,0.9300,
,,0.3012,0.2555,0.0423,86.04,-3.96,33.95
5,705268.50,3913632.50,190.49,705268.469,3913631.984,0.554,0.040,171.39,0.956
5,,,0.4450,0.0697,0.0010,344.23,77.09,-48.36
```

APPENDIX D. MTADS EM61 MKII ARRAY PERFORMANCE AT THE STANDARDIZED UXO TECHNOLOGY DEMONSTRATION SITES

The Chemistry Division of the Naval Research Laboratory has participated in several programs funded by SERDP and ESTCP whose goal has been to enhance the discrimination ability of the MTADS for both the magnetometer and EM-61 array configurations. The process was based on making use of both the location information inherent in an item's magnetometry response and the shape and size information inherent in the response to the time-domain electromagnetic induction (EMI) sensors that are part of the baseline MTADS in either a cooperative or joint inversion. As part of ESTCP Project 199812, a demonstration was conducted on a live-fire range, the 'L' Range at the Army Research Laboratory's Blossom Point Facility [1][a]. In 2001, a second demonstration was conducted at the Impact Area of the Badlands Bombing Range, SD [2] as part of ESTCP Project 4003. In all these efforts, our classification ability has been limited by the information available from the time-domain EMI sensor. The EM61 is a time-domain instrument with either a single gate to sample the amplitude of the decaying signal (MkI) or four gates relatively early in time (MkII). The first generation of the MTADS EM61 MkII array was demonstrated in 2001 [2] at the Badlands Bombing Range, SD with little demonstrable gain over the single decay of the MkI array. A second generation of the MkII array with updated electronics was constructed in 2003 as part of ESTCP Project 200413.

The upgraded MTADS EM61 MkII array was demonstrated at both of the Standardized UXO Technology Demonstration Sites located at the Aberdeen and Yuma Test Centers in 2003 and 2004 [3]. At each of the sites, the Calibration Lanes, the Blind Test Grid (if available), and as much of the Open Field Area as was possible were surveyed. The scoring results are the basis for characterizing the success of the demonstrations and the performance of the array. The Open Field results are presented here to demonstrate the performance of the MTADS EM61 MkII Array.

D.1 ABERDEEN PROVING GROUND OPEN FIELD

Selected results from our surveys at the Open Field at the Aberdeen Proving Ground Standardized UXO Test Site have been provided to us by analysts at the Institute for Defense Analyses. These results are summarized graphically in the following sections.

D.1.1 RESPONSE STAGE

Response stage results for the APG Open Field scenario are shown in Figure D-1 and Figure D-2. The results are analyzed by excluding first items that were not covered by

[a] References are located at the end of the Appendix, not in the main document.

the survey or are within 2-m of another item then retaining those exclusions and further excluding items deeper than 11x their diameter.

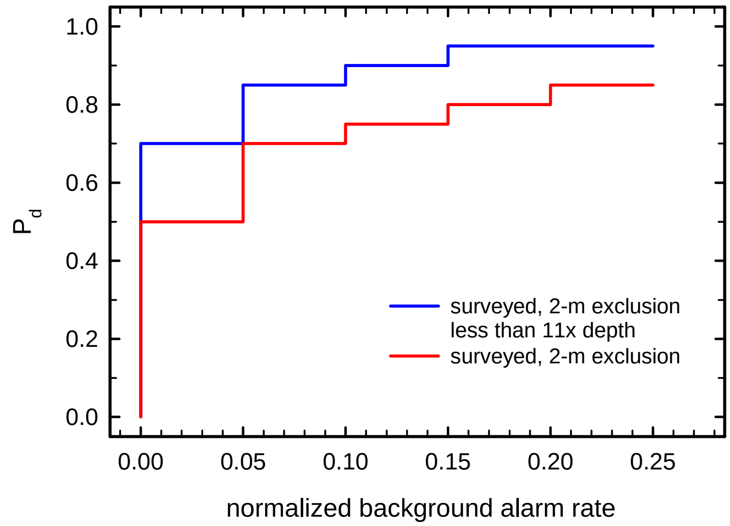

Figure D-1 – MTADS EM61 MkII array detection performance at the APG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

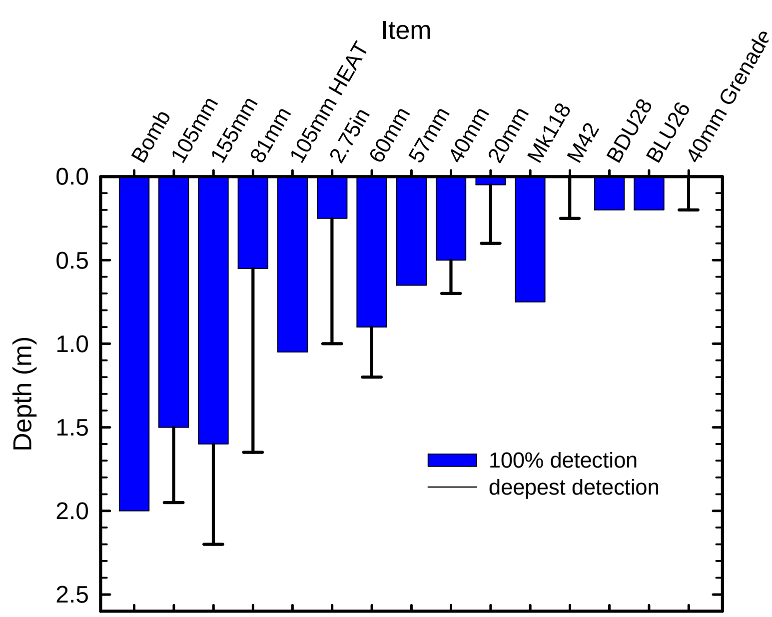

Figure D-2 – MTADS EM61 MkII array response stage results for the APG Open Field scenario broken out by target type

D.1.2 DISCRIMINATION STAGE

Discrimination Stage results from the APG Open Field are shown in Figure D-3. Exclusion of items that are deeper than 11x their diameter improves performance.

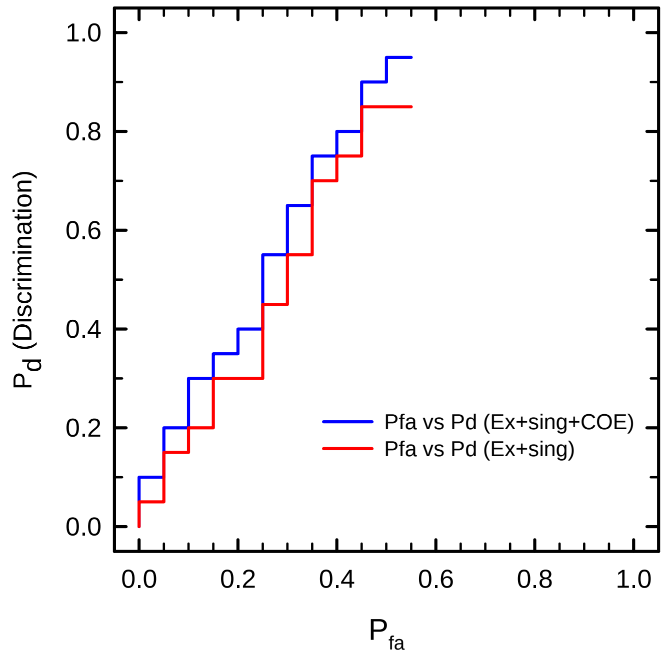

Figure D-3 – MTADS EM61 MkII array discrimination performance at the APG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

D.2 YUMA PROVING GROUND OPEN FIELD

Selected results from our surveys at the Open Field at the Yuma Proving Ground Standardized Test Site have been provided to us by analysts at the Institute for Defense Analyses. These results are summarized graphically in the following sections.

D.2.1 RESPONSE STAGE

Response stage results for the YPG Open Field scenario are shown in Figure D-4 and Figure D-5. The results are analyzed by excluding first items that were not covered by the survey or are within 2-m of another item then retaining those exclusions and further excluding items deeper than 11x their diameter. Notice that the background alarm rates in Figure D-4 are more than a factor of ten smaller than the corresponding results from Aberdeen. Although the Yuma site is more geologically active than Aberdeen, it is smoother so there were fewer false alarms due to platform bouncing over deep ruts. Detection depths at Yuma, in general, are deeper than at Aberdeen but follow a similar trend in terms of detection depth by munitions type. Note in particular the improved detection performance for the 81mm mortar, the 2.75-in rocket, the M42 submunition,

and the 40mm grenade. As a counter example, the detection depth (both 100% and maximum) for the 57mm projectile was 0.44m (8x) at Yuma and 0.65m (11x) at Aberdeen.

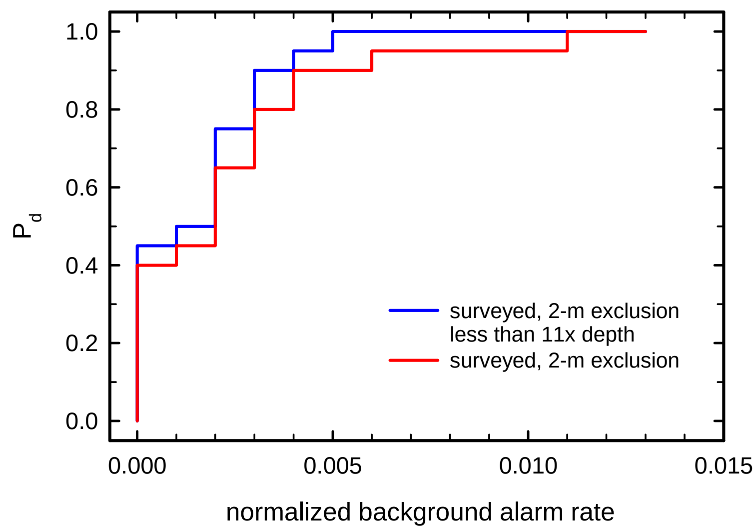

Figure D-4 – MTADS EM61 MkII array detection performance at the YPG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

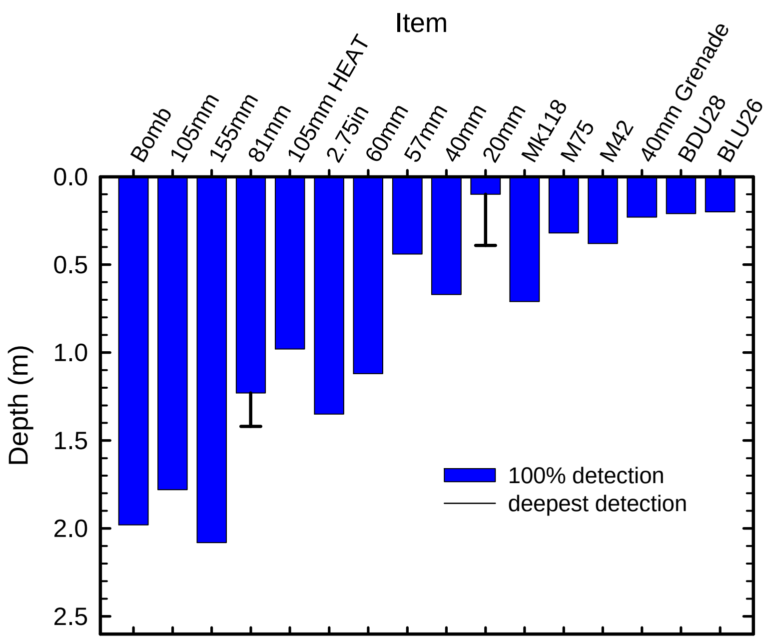

Figure D-5 – MTADS EM61 MkII array response stage results for the YPG Open Field scenario broken out by target type

D.2.2 DISCRIMINATION STAGE

Discrimination Stage results from the YPG Open Field are shown in Figure D-6. Exclusion of items that are deeper than 11x their diameter improves performance. Discrimination performance, as a whole, is lower at the Yuma site than for the Aberdeen site. This is counter to the trend seen for the response stage results. In the case of the response stage, the improved performance was attributed to reduced platform motion noise due to more benign microtopography.

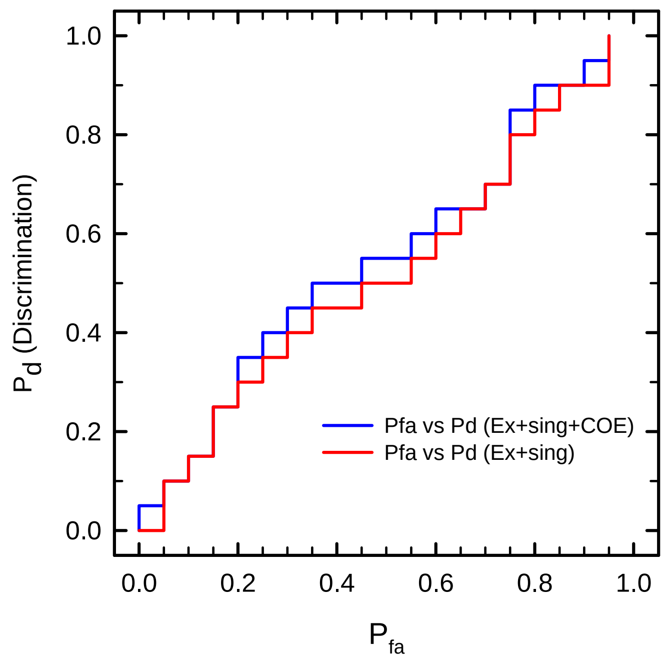

Figure D-6 – MTADS EM61 MkII array discrimination performance at the YPG Open Field Scenario. The red line is derived considering only targets that were covered in the survey and are not within 2 m of another target. The blue line retains those criteria and also excludes targets deeper than 11x their diameter.

D.3 REFERENCES

1. "Electromagnetic Induction and Magnetic Sensor Fusion for Enhanced UXO Target Classification," H.H. Nelson and B. Barrow, NRL/PU/6110—00-423.

2. "Advanced MTADS Classification for Detection and Discrimination of UXO," H.H. Nelson, T.H. Bell, J.R. McDonald, B. Barrow, NRL/MR-MM/6110—03-8663.

3. "Survey of Munitions Response Technologies," ESTCP, ITRC, and SERDP, June, 2006.